IDA

INSTITUTE FOR DEFENSE ANALYSES

Activities Related to Systems Engineering

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PREFACE

This document supports work performed by the Institute for Defense Analyses (IDA) in partial fulfillment of the task titled "Systems Engineering in the Acquisition Process." The work was sponsored by the Office of the Under Secretary of Defense (Acquisition, Technology, and Logistics), Office of Defense Systems, Office of Systems Engineering.

This document explores the different ongoing activities within the government, academia, and industry to promote the discipline of and the implementation of systems engineering. The focus is systems engineering within the defense community, although attention is given to non-defense endeavors both within the United States and internationally. The research performed for this document took place from roughly spring 2003–fall 2004, and therefore, the activities presented in this document represent merely a snapshot in time. For this reason, readers are encouraged to seek the most up-to-date information on an activity via the various links provided.

The authors wish to thank Dr. Wolter Fabrycky and Dr. Dinesh Verma for sharing their systems engineering educational databases, which served as the starting point for appendices A and B of this document. In addition, the authors wish to thank the reviewer, Lance Hancock of the System Evaluation Division of IDA and editor, Shelley Smith of the Strategy, Forces, and Resources Division of IDA for their comments and recommendations.

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I. INTRODUCTION

The importance of systems engineering in weapon system development programs, particularly in this era of systems of systems on the battlefield, cannot be over-emphasized. Recently, various senior Department of Defense (DoD) officials have voiced the opinion that the systems engineering process is "broken." For example, former Secretary of the Air Force James Roche has said, "Many of our current system acquisition programs are suffering from a lack of attention to or inconsistent application of good systems engineering principles."[1] This paper—and an accompanying paper, *An Examination of the Issues Surrounding a National Institute of Systems Engineering* (IDA Paper P-3849)—report the results of a project undertaken by the Institute for Defense Analyses (IDA) to determine the extent of the "problem" with systems engineering, investigate ongoing activities that promote systems engineering, and consider the potential of using other ongoing efforts and activities to strengthen systems engineering within DoD.

This document is intended to serve as a reference for the IDA Paper P-3849, E*xamination of the Issues Surrounding a National Institute of Systems Engineering.* Various ongoing activities and efforts to promote systems engineering were identified during IDA's effort to explore the need for a National Institute for Systems Engineering and to determine the structure and focus if such an organization came to fruition.

This document addresses the topics as they pertain to systems engineering:

- DoD Efforts
- Efforts in Other Government Agencies
- Associations
- Standards and Models
- Academic Opportunities
- Academies, Centers, and Labs

Three appendices give details on the undergraduate, graduate, and certificate programs available in systems engineering in the United States as of January 2004.

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[1] 1st Lt Ellen Kowalchuk, "AFIT stands up center for systems engineering," Air Force Institute of Technology Public Affairs, AFMC News Service Release 0211, 10 February 2003.

II. DOD EFFORTS

In this chapter, efforts that are already underway within DoD related to systems engineering are described and other activities that could be leveraged to promote good systems engineering are also discussed.

A. REORGANIZATION WITHIN OSD

One indicator of the importance of systems engineering to the Department of Defense is the 2002 reorganization within the Office of the Secretary of Defense (OSD), resulting in the reconstitution of the Office of Systems Engineering (SE) under the Director of Defense Systems. The mission of this newly formed SE Office, as stated by the Director of Defense Systems, is summarized as follows:

- Raise awareness of the importance of good systems engineering within DoD
- Ensure that program managers apply good practice in the execution and planning of programs
- Assess the performance of those who carry out programs
- Define what constitutes good systems engineering practice, avoiding theoretical generalizations
- Capture, share, and ensure the application of best practice in design, development, production, and support
- Promote the use of sound engineering management tools and the development of new tools and methods
- Collaborate with the Services, academia, professional associations, and industry
- Promote acquisition learning in the area of systems engineering for both the government workforce and private sector
- Set policy for systems engineering practice and see to its implementation
- Lead assessment of engineering capability and progress and provide independent expert program review support to program managers as requested
- Provide systematic analysis of acquisition issues to identify causal factors contributing to capability delivery problems

The SE Office's mission under Defense Systems has emerged in an environment favorable to systems engineering within Acquisition, Technology and Logistics (AT&L) overall. Within this context, the importance of systems engineering has been highlighted in policy, as well as corresponding guidance. In order to accomplish this work, the SE

Office is subdivided into three offices—Enterprise Development, Developmental Test & Evaluation, and Assessments & Support—which work on all aspects of DoD systems engineering revitalization from drafting policy and evaluating the existing opportunities for training to education, as well as early involvement with programs with respect to systems engineering policy and implementation. The outreach activities often involve teams of systems engineering experts called "Green Teams."

1. Systems Engineering Policy

The importance of systems engineering has been highlighted several times within DoD policy. One such recent official boost for systems engineering is evident in the 12 May 2003 revision of DoD Directive 5000.1, "The Defense Acquisition System." The revised 5000 Directive includes specific language on systems engineering in its Enclosure 1, Additional Policy, as follows:

> E1.27. Systems Engineering. Acquisition programs shall be managed through the application of a systems engineering approach that optimizes total system performance and minimizes total ownership costs. A modular, open-systems approach shall be employed, where feasible. (p. 7)

Systems engineering was further championed in a 20 February 2004 memo signed by the Acting Under Secretary of Defense for Acquisition, Technology and Logistics (USD (AT&L)) titled "Policy for Systems Engineering in DoD." An introductory memo signed by the Director of Defense Systems states that the USD(AT&L) has "established a goal to rejuvenate the systems engineering process and drive good systems engineering back into the way we do business."[2] In the body of the memorandum, the USD(AT&L) makes the case that the "[a]pplication of rigorous systems engineering discipline is paramount to the Department's ability to meet the challenge of developing and maintaining needed warfighter capability." To this end, he directed that the following policy go into effect immediately and be incorporated into the next revision of DoD 5000:

> Systems Engineering. All programs responding to a capabilities/ requirements document regardless of ACAT shall apply a systems engineering approach that optimizes total system performance and minimizes total ownership costs. Programs shall develop a Systems Engineering Plan approved by the MDA in conjunction with each Milestone review and summarized in the Acquisition Strategy. This plan

[2] Glenn F. Lamartin, Director, Defense Systems, "Policy for Systems Engineering in the Department of Defense," Memorandum, 18 December 2003.

> shall describe the program's overall technical approach, including processes, resources, and metrics. It shall also detail the timing and conduct of systems engineering technical reviews. [3]

The memo further states that the Director of Defense Systems shall support this policy by providing Systems Engineering Plan guidance for inclusion in DODI 5000.2 and the *Defense Acquisition Guidebook* (DAG); assessing and recommending any changes to the "current Department-level systems engineering related policies, practices, guidance, tools, and education and training;" establishing and leading a senior-level systems engineering forum; and reviewing the Systems Engineering Plans for programs for which it is the Milestone Decision Authority. This memo also calls upon those Services and agencies with acquisition responsibilities to identify a senior-level representative to participate in the above-mentioned systems engineering forum, as well as "to provide the Director, Defense Systems, its approach and recommendations on how we can ensure that application of sound systems engineering discipline is an integral part of overall program planning, management and execution within both government and industry."[4] A policy addendum followed on 22 October 2004.[5]

2. Systems Engineering Chapter of the Defense Acquisition Guidebook

In keeping with the task of providing systems engineering guidance related to the new DoDD 5000.1, the Systems Engineering Office under Defense Systems has been engaged over the past year in the development of a "Systems Engineering" chapter for inclusion in the *Defense Acquisition Guidebook*. This chapter (fourth in the guidebook) comprises six different sections:

> (4.1) *Systems Engineering in DoD Acquisition* provides a definition of systems engineering and its relationship to acquisition, while also illustrating the role of program managers in systems engineering and how systems engineering processes can be used to define engineering specifications from user capabilities.
>
> (4.2) *Systems Engineering Processes: How Systems Engineering is Implemented* introduces a new set of processes from those previous associated DoD grouped into technical management and technical process categories.

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[3] Michael W. Wynne, Acting Under Secretary of Defense for Acquisition, Technology and Logistics, "Policy for Systems Engineering in DoD," Memorandum, 18 December 2003.

[4] Ibid.

[5] Michael W. Wynne, Acting Under Secretary of Defense for Acquisition, Technology and Logistics, "Policy Addendum for Systems Engineering," Memorandum, 22 October 2005.

(4.3) *Systems Engineering in the System Life Cycle* highlights the application of an integrated technical framework for systems engineering processes through the acquisition phases of a system's life cycle.

(4.4) *Systems Engineering Decisions: Important Design Considerations* introduces the many design considerations (e.g., reliability; maintainability; environment, safety, and occupational health; etc.) to be taken into account in the development of a system.

(4.5) *Systems Engineering Execution: Key Systems Engineering Tools and Techniques* discusses methodologies, techniques, and tools to assist in implementing various aspects of the systems engineering processes.

(4.6) *Systems Engineering Resources* provides a list of systems engineering related resources from government, industry and academia is provided.

3. Systems Engineering Plan and Guidance

One major component of the revitalization of systems engineering within DoD has been renewed focus on Systems Engineering Plans. The original policy memo signed by the Acting USD(AT&L) stipulated that "all programs responding to a capabilities or requirement document … shall develop a Systems Engineering Plan (SEP) for Milestone Decision Authority (MDA) approval in conjunction with each Milestone review" and assigned Defense Systems with the responsibility for providing guidance on Systems Engineering Plans (SEP). In response, the Director of Defense Systems issued a memorandum on 30 March 2004, titled "Implementing Systems Engineering Plans in DoD—Interim Guidance." The SEP is intended to be established early in the definition of a program in a way that it becomes a living document tailored to that specific program. DoD does not prescribe a specific SEP format; however, a "SEP describes the program's overall technical approach, including systems engineering processes; resources; and key technical tasks, activities and events along with their metrics and success criteria," as well as providing the linkage between the technical and overall program planning aspects of the program. Key items for inclusion are as follows: [6]

- The systems engineering processes to be applied by the program
- The system's technical baseline approach

[6] Glenn F. Lamartin, "Implementing Systems Engineering Plans in DoD— Interim Guidance," Memorandum, 30 March 2004.

- Event-driven timing, conduct, success criteria, and expected products of technical reviews
- The integration of systems engineering into the program's integrated product teams (IPTs)

Since this memo represented only interim guidance, an effort has also been under way under the auspices of a Systems Engineering Plan Working Group formed by the Systems Engineering Office. The SEP Working Group has produced a SEP Preparation Guide, version 0.95, and SEP Focus Areas for Technical Planning.

B. DEFENSE ACQUISITION UNIVERSITY

The Defense Acquisition University (DAU) currently provides the acquisition, technology, and logistics workforce with life-long learning resources 7 days a week and 24 hours a day. Innovative strategies to accomplish this include distributive learning, performance support, communities of practice, and continuous learning modules. Within its mission, DAU provides the following for the acquisition, technology, and logistics functional areas and career field/paths set forth in the Defense Acquisition Workforce Improvement Act (DAWIA) (listed in Table II-1):

- Certification training
- Assignment-specific training
- Research programs
- Consulting and performance support
- Knowledge management
- Strategic partnerships with other government agencies, industry, and academia
- Equivalencies
- Publications

In addition to conducting education and training, DAU assists Program Manager offices, as well as other agencies, with consulting and performance support to Program Manager offices, as well as other agencies on systems engineering techniques and methods. In doing both activities, DAU has established many partnerships with academia and industry, including Lockheed Martin, which has invited DAU to sit on its Systems Engineering Education Council.

In particular, DAU offers a number of services in the area of systems engineering. DAU is responsive to customer requirements and the opportunity exists to leverage any of their services.

Table II-1. DAWIA Functional Areas and Career Fields/Paths

Functional Area	Career Fields and Paths
Acquisition Management	Program Management
Auditing	Auditing
Business, Cost Estimating, and Financial Management (BCEFM)	BCEFM
Facilities Engineering	Facilities Engineering
Information Technology	Information Technology
Logistics	Life Cycle Logistics
Procurement & Contracting/ Government Property	Industrial/Contract Property Management
	Contracting
	Purchasing
Science and Technology	Systems Planning, Research, Development and Engineering (SPRDE)—Science and Technology Manager (STM)
Technical Management	Production, Quality and Manufacturing (PQM)
	Systems Planning, Research, Development and Engineering (SPRDE)—Systems Engineering (SE)
	Test and Evaluation (T&E)

Source: FAs and Career Fields were taken from DAU 2004 Catalog, pp. 5 and 19, http://www.dau.mil/catalog/default.aspx (accessed 10 August 2004). Career Path information was taken from ACC http://acc.dau.mil/simplify/ev.php?ID=10106%20201&ID2=DO%20TOPIC (accessed 10 August 2004). Match up between the FAs and Career paths was assisted by the LMI Report, http://gravity.lmi.org/futurewf/ (accessed 10 August 2004), section 5, p. 18.

1. Systems Planning, Research, Development and Engineering Coursework

DAU provides a systems engineering career path within its Systems Planning, Research, Development and Engineering (SPRDE) career field, which offers Career Field Level II and Level III certifications.[7] A revamped Level I certification is also being considered. Courses associated with this SPRDE track are systems engineering-related and many of the subjects that are part of the systems engineering process are covered, including System Architecture, Risk Management, Systems Design, and Software Management. The SPRDE Functional Integrated Product Team (FIPT) is presently reviewing the current systems engineering courses and their corresponding learning objectives and will be making recommendations to DAU for the revision of SYS201,

[7] DAWIA establishes three levels of certification. Generally, a member of the AT&L workforce strives for Level III certification in his or her primary career field.

"Intermediate Systems Planning, Research, Development and Engineering," and SYS 301, "Advanced Systems Planning, Research, Development and Engineering," as well as the development of a new course, SYS101, presumably to be titled, "Introduction to Systems Planning, Research, Development and Engineering." This revision of the SPRDE curriculum envisions a new framework in which SYS101, SYS201, and SYS301 predominately address the 16 systems engineering technical requirements processes, the application of systems engineering by phase, and systems engineering leadership and planning, respectively. The new SPRDE course content target to be established is October 2005. The SPREDE FIPT has also made recommendations to and are working with other career field FIPTs to get additional systems engineering-related content incorporated into other courses, such as Acquisition, Program Management, Logistics, and Finance.

2. Systems Engineering Community of Practice

The Systems Engineering Community of Practice (SE CoP) is a part of the Acquisition Community Connection[8] and resides on the DAU Web server. It is formatted to be consistent with Chapter 4 of the Defense Acquisition Guide. The target audience is the acquisition workforce. The goal of the SE CoP is to "develop into the source for reproducible, innovative systems engineering solutions." The strategy to achieve this goal is through "insightful discussions about complex issues, innovative coordinated actions, interactions between members of the community, and the enrollment of other communities."[9] In order to do this, the community has to involve systems engineering societies, academia, and industry. This Web-based SE CoP also provides links to the International Council on Systems Engineering (INCOSE) as a collaborative environment that will be available to all of DoD and Industry.

3. Continuous Learning Modules

On 13 September 2002, Under Secretary of Defense for Acquisition, Technology, and Logistics, E.C. Aldridge, Jr., issued a memorandum that updated and streamlined the continuous learning requirements for the acquisition, technology, and logistics workforce.

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8 The ACC also includes the Program Management, Contract Management, Risk Management, Logistics Management, and Facilities Engineering communities and the special interest areas of Acquisition Research; Information Technology; Spectrum Compliance; Environment, Safety, and Occupational Health; Performance Based Service Acquisition; and Total Ownership Cost.

9 Briefing by T.J. Junor, SE CoP Co-Lead, OASN(RD&A)ARO.

New requirements were for a mandatory 80 hours of continuous learning points within 2 years, including certification training required by the DAWIA.

Currently DAU offers more than 50 Continuous Learning (CL) opportunities, including online, self-paced modules with assessments and certifications as well as presentations intended for awareness only.[10] Continuous learning modules with relevance to systems engineering presently offered by DAU include —

- Earned Value Management (EVM)
- Fundamentals of the Integrated Product Teams
- Incentives for reducing total ownership cost
- Lean enterprise concepts
- Requirements generation
- Risk management
- Six sigma: concepts and practices
- Work breakdown structure overview

The SPRDE FIPT has also been involved in providing recommendations for and a prioritization of continuous learning module (CLM) topics. In FY04, this included the development of systems engineering-related CLMs for ISO 9000, Reliability and Maintainability, Joint and Multi-Test and Evaluation, and Technical Reviews. Additional CLMs that are in development include System Safety in Systems Engineering Organizations and Modeling and Simulation in Systems Engineering. FIPT recommendations for future development include such topics as Systems Engineering Planning and Contracting for Systems Engineering.

4. Publications

One of the publications distributed by DAU is *Systems Engineering Fundamentals*. Published in January 2001, it reflects the changes in the DoD 5000 series as of that date. Topics include the systems engineering problem-solving process, including requirements analysis, functional analysis and allocation, design synthesis and allocation, and verification; systems analysis and control, including risk management, configuration management, and trade studies; and the planning, organizing, and management of systems. This guide provides "a basic, conceptual-level description of systems engineering management as it relates to the development and life cycle

[10] DAU, Chapter 4: Course Descriptions, p. 74.

management of a system—including basic concepts, problem-solving, tools to balance the process, and issues integral to the systems engineering management effort."[11]

C. AIR FORCE

This section summarizes various systems engineering-related programs, efforts, and activities already undertaken by the U.S. Air Force (AF) and some other activities that could be leveraged to help promote systems engineering.

1. Air Force Material Command Systems Engineering Revitalization Program

Air Force Material Command (AFMC) initiated its Systems Engineering Revitalization Program in February 2002. It sponsored the Airworthiness and Operational Safety, Suitability, and Effectiveness (OSS&E) Initiatives that—

- Finalized policy Directives and Instructions in FY00
- Developed detailed guidance and training for OSS&E product centers
- Defined product line technical responsibility and assigned product centers
- Developed unit compliance inspection requirements for engineering professionalism and OSS&E to ensure rigor

As part of its revitalization effort, AFMC instituted the Year of the Engineer and Scientist (YES) to emphasize the criticality of engineers and scientists and is also conducting the following activities:

- Creating the "Systems Engineering for Everyone" guide with corresponding training
- Championing systems engineering education and training
- Participating in the International Council on Systems Engineering (INCOSE), the National Defense Industrial Association (NDIA), and the Aerospace Industrial Association (AIA)
- Establishing engineering organizations at Air Logistics Centers with a systems engineering point of contact identified at all centers.

2. Air Force Institute of Technology

In July 2002, the AF Chief Scientist, Dr. Alexander Levis, visited Wright-Patterson Air Force Base (WPAFB) to work with the Air Force Institute of Technology (AFIT) to restructure its Master of Science program in systems engineering. In August 2002, Dr. Levis then conducted the first Academic Advisory Board meeting at WPAFB.

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[11] This document is available on the DAU website at http://www.dau.mil/pubs/gdbks/sys_eng_fund.asp.

Part of the revamping of the systems engineering curriculum at AFIT is to include the architecture-based approach promoted by Dr. Levis.[12] A graduate systems engineering certification program for experienced engineers was created, and policy was changed to allow senior enlisted personnel to attend AFIT. In October 2002, AFIT initiated its first classes in the revised systems engineering masters degree and certificate programs, with an enrollment of over 30 engineers.

New courses include a 4-hour Systems Engineering Orientation course, a 40-hour Systems Engineering Application course, and something called the Systems Engineering Pocketbook. These courses are part of the effort to educate all personnel involved in programs on the importance of systems engineering. This importance of expanding systems engineering knowledge is illustrated by a 2- to 4- hour Introduction to Systems Engineering intended as an orientation course specifically targeted at non-engineers.[13]

In December 2002 the Air Force and Navy established an educational alliance between AFIT and NPS to leverage the capabilities and resources of both while eliminating duplication. This alliance is structured to enhance the educational opportunities for personnel in both Services.[14] Within this arrangement AFIT is the DoD center of excellence for aeronautical-engineering education and NPS is likewise for acquisition-management and meterology graduate education. This AFIT-NPS alliance is further enhanced by having "an Air Force colonel as the deputy superintendent and chief of staff of the NPS and a Navy captain as the vice commandant and director of staff at AFIT."[15]

3. Center for Systems Engineering

In 2002, under direction from the Secretary of the Air Force to form an "institute" of systems engineering, the Air Education and Training Command (AETC) broadened the AFIT mission and organization, which included the creation of a Center for Systems

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12 Alexander H. Levis, "DoD Architectures in Systems Engineering—Solution or Problem?," Keynote address at the Conference on Systems Integration, Stevens Institute of Technology, Hoboken, NJ, 13 March 2003.

13 Mike Ucchino, "Center for Systems Engineering," Briefing to NDIA SE Division Meeting, 19 February 2004.

14 Dr. James G. Roche, "Acquisition and Logistics Excellence—Exactly," Remarks for the Acquisition and Logistics Excellence Day, Wright-Patterson Air Force Base, OH, 21 October 2002; and "Building the Air Force of the Future," Remarks to the Air Force Association Air Warfare Symposium, Orlando, FL, 14 February 2003.

15 Staff Sgt. A.J. Bosker, "AF, Navy form alliance to better meet education needs," Air Force Link website, http://www.af.mil/stores/story.asp?storyID=121902367, 19 December 2002.

Engineering (CSE) in February 2003. The two overarching goals of the CSE are as follows:[16]

- To educate the workforce (capability definers, system architects, engineers and program managers) in how systems engineering both benefits them and is appropriately applied throughout a system lifecycle from identification of need, to alternative concept analysis, to concept refinement, to system definition and design through qualification, modification and sustainment
- To influence and institutionalize systems engineering in both the capability development process and the complex systems acquisition and sustainment processes

The CSE exists as a directorate within AFIT. The roles and responsibilities of the Center include an education component (education and training) and a practitioner component (consultation, advocacy, and collaboration) related to systems engineering. The Center has some full-time staff but will also have access to a list of experts and rotational and support staff in addition to AFIT personnel. The rotational positions will be important steps in the development of Chief Systems Engineers and other future systems engineering leaders. Industry participants will gain an enhanced DoD/AF perspective.[17]

Organizationally, there is a Systems Engineering Senior Council, consisting of the AFIT Commandant and representatives from the Air Education and Training Command (AETC), the AFMC, the Air Force Space Command (AFSPC), Headquarters of the USAF, Department of Defense, other government agencies, industry, and academia, to provide strategic direction and vision for the Center to the AETC Commander. Mr. Mark Wilson was the initially interim CSE Director and now is fully installed in the position.

4. Memorandum to Incentivize Contractors for Better Systems Engineering

On 6 January 2003, the Assistant Secretary of the Air Force, Marvin Sanbur, released a memorandum titled "Incentivizing Contractors for Better Systems Engineering." This memorandum directed programs to elevate systems engineering to a "level commensurate with cost and schedule." Dr. Sanbur called this an Air Force transformation imperative. The memorandum gave direction for ensuring necessary and sufficient attention to systems engineering processes and practices on all existing and future acquisition programs. Ways to ensure this attention include joint cooperative efforts with contractors, performance incentives, and explicit identification of key

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16 "Who We Are," Center for Systems Engineering website, http://cse.afit.edu.

17 Mark K. Wilson, *Center for Systems Engineering: Status Briefing to NDIA SED*, 6 February 2003.

systems engineering processes and practices in acquisition program documentation. Additionally, the memo promised to identify ways to improve systems engineering throughout the acquisition process through education and training; policies, instructions, and guidance; and the use of the Acquisition Center of Excellence and the Center for Systems Engineering. All efforts stemming from this memorandum were seen as "Spiral 1" in a continuing effort to review and enhance the systems engineering process with respect to USAF programs. Attachments to the memorandum gave examples of award fee and incentive fee plan provisions and sample lists of systems engineering tools, documents, and resource information.[18]

5. Guide for Engineering Robust Systems

In 2004 the Air Force released *Guidance for the Use of Robust Engineering in Air Force Acquisition Programs*. Through this guidance the Air Force relates robust engineering to the use of disciplined systems engineering processes. This document was not conceived of as a guide for the implementation of systems engineering processes, but rather "defines the role of [systems engineering] in the overall execution, management and control of Air Force acquisition programs."[19]

In presenting this guidance the Air Force clarifies its systems engineering revitalization objectives as follows: [20]

- Establish an environment founded on [systems engineering] principles [in which] products that exhibit attributes of robustness:
  - Deliver promised capabilities within budget and schedule
  - Are easily scalable/expandable to meet future capability needs
  - Are desensitized to expected variabilities in manufacture and use
- Reintroduce and elevate key elements of [systems engineering] as principal considerations in solicitation, award, and execution processes
- Provide sample leading indicators for proactive systems engineering that:
  - Are measurable
  - Map to incentive strategies
  - Minimize surprises.

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18 Marvin R. Sambur, Assistant Secretary of the Air Force (Acquisition), "Incentivizing Contractors for Better Systems Engineering," SAF/AQ Memorandum for all PEOs/DACs/Single Managers, 6 January 2003.

19 "Guidance for the use of Robust Engineering in Air Force Acquisition Programs," 8 July 2004, p. 1.

20 Ibid., p. 1.

This guidance document illustrates systems engineering through two "classic" graphics associated with the discipline—the Systems Engineering Vee Model and the 499B Systems Engineering Engine. More specific information is included on robust design methodologies and proposal guidance for effective systems engineering, including example contract language, means to incentivize systems engineering, and technical management leading indicators related to cost/schedule/performance risk in a program.

6. Lean Aerospace Initiative

In May 1993 the predecessor to the Lean Aerospace Initiative (LAI), the Lean Aircraft Initiative, was created in partnership with the Air Force as a consortium between leading US aerospace companies and MIT "as a response to challenges facing the aerospace industry, including such previously held tenets as 'affordability rather than performance at any cost.'"[21] The LAI became the Lean Aerospace Initiative in 1998 with the expansion of the consortium to include the U.S. space sector. Overall, the LAI's mission is "to research, develop and promulgate practices, tools, and knowledge to enable and accelerate the envisioned transformation of the greater US aerospace enterprise through people and processes."[22] One such effort under the auspices of the LAI is the Lean Systems Engineering Working Group. The purpose of this special interest group is "to discuss the intellectual convergence of lean principles and systems engineering, and how lean can be integrated best into graduate level systems engineering courses."[23]

At the beginning of 2004, Dr. Sambur, Assistant Secretary of the USAF for Acquisition, asked the LAI to take a look specifically at how the consortium could "contribute to the Air Force's initiative to revitalize Systems Engineering."[24] Since then, an LAI Action Team for Revitalizing Systems Engineering has been established and the Systems Engineering Revitalization initiative has been the topic of discussion in various LAI forums, including a special breakout session at the LAI's March 2004 Plenary Conference, as well as other meetings and workshops. One such workshop was an August 2004 Air Force/LAI Workshop on Systems Engineering for Robustness, which further addressed this initiative focusing on recommending several new leading indicators

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21 *Lean Aerospace Initiative Information Sheet*, MIT 2003.

22 Ibid.

23 Ibid.

24 "LAI News #222," Email from Juliet Perdichizzi, 27 February 2004.

for systems engineering to supplement the set of leading indicators published in the *AF Guide for Engineering Robust Systems*.[25]

7. Space & Missile Systems Center

At the beginning of 2004, the United States Air Force Space and Missile Systems Center (SMC) published the second edition of its *SMC Systems Engineering Primer & Handbook: Concepts, Processes, and Techniques*. Developed to coordinate with SMC systems engineering training courses, "[t]his Systems Engineering handbook is written to provide SMC personnel with fundamental systems engineering concepts and techniques as they apply to space and launch systems and the SMC environment. The audience includes the project officer, junior systems engineer, an engineer in another discipline that must perform Systems Engineering functions, or the experienced engineer who needs a suitable reference."[26] In addition to providing a Systems Engineering Primer, which attempts to answer such questions as what is systems engineering and why is it useful, this document contains chapters as follows:[27]

- How does the Systems Engineering Process work?
- Life Cycle Phases of a Major System
- What is System Engineering Management?
- What are the System Engineer's Tools?
- What are the Companion Disciplines to Systems Engineering?
- Validation and Verification

Furthermore, the publication announces that the SMC's Systems Engineering Revitalization (SER) initiatives will likely introduce further changes in engineering and acquisition at the SMC over the next several years.

8. Air Force Academy

Beginning in fall 2003, the Air Force Academy will offer a bachelor's degree in systems engineering. This is part of the Air Force's systems engineering revitalization efforts spearheaded by Dr. Alex Levis, Chief Scientist of the Air Force, and is part of a broader effort to change the curriculum to place greater emphasis on science. The Academy currently offers courses in the more traditional fields of electrical engineering,

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25 "LAI News #235," Email from Geoffrey A.P. Groesbeck, 27 August 2004.

26 Space & Missile Systems Center, U.S. Air Force, *SMC Systems Engineering Primer & Handbook: Concepts, Processes, and Techniques*, 15 January 2004, p. xii.

27 Ibid, p. iii-vi.

aeronautical and astronautical engineering, mechanical engineering, and even engineering mechanics. Some systems-related courses can be found among the course offerings for these more traditional engineering disciplines. By offering a systems engineering degree at the undergraduate level, the Air Force will be on a par with the other Services.

9. Education with Industry Program

The Education with Industry (EWI) program is jointly sponsored by AFIT and industry to provide "Air Force officers and civilians with on-the-job education, experience, and exposure to civilian industrial environments not available through formal courses of instruction."[28] This program or something related to it could be used to help in the field of systems engineering.

D. NAVY

This section summarizes various systems engineering-related programs, efforts, and activities already undertaken by the U.S. Navy to enhance systems engineering processes and practice.

1. Naval Air Systems Command (NAVAIR) Initiatives

The Naval Air Systems Command has instituted several Systems Engineering Organizational and Process Initiatives, including—

- A Common Systems Engineering Process based on ANSI/EIA-632, *Processes for Engineering a System*, and documented in a Systems Engineering Guide that specifies particular methods and/or tools for implementation
- Communities of Practice
- Systems engineering expert teams (called Green Teams)
- Mentoring
- Training and certification
- Yellow pages
- Common configuration control management process
- Aviation/ship/warfare system integration process
- Risk management instruction with risk checklists
- Systems Engineering Technical Review (SETR) process instruction and handbook

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[28] AFIT website, http://ci.afit.edu/CIG/CIGH/EWI%20Features.htm (last updated 3 April 2001).

The *NAVAIR Systems Engineering Guide*, risk management instruction and checklists, and *Systems Engineering Technical Review* process instruction and handbook are described in more detail in the following sections.

a. NAVAIR Systems Engineering Guide

In 1999 NAVAIR created a NAVAIR Systems Engineering Process Working Group (SEPWG) to develop an addendum to EIA-632, as a NAVAIR guide. The resulting *NAVAIR Systems Engineering Guide* includes the EIA-632 standard and additional information for members of the Naval Air Systems Team, which is highlighted. This modification of EIA-632 applies only to NAVAIR and addresses how NAVAIR addresses the "what to do" described in the standard. NAVAIR then uses the Integrated Capability Maturity Model, developed by the SEI, as a basis and means for determining "how well" the processes of EIA/EIA-632 are defined and implemented.[29]

b. Systems Engineering Technical Review Process

The Navy issued NAVAIR Instruction 4355.19B, *Systems Engineering Technical Review Process*, in June 2003 "to establish policy, outline the process, and assign responsibilities for the planning and conduct of SETRs of Naval Air Systems Command (NAVAIR) programs."[30] As an integral component of the systems engineering process and life cycle management, this policy states that the "Program, Assistant Program Manager or Systems Engineering (APMSE) and Assistant Program Logistics (APML), as part of the program team, shall ensure that planning for SETRs is fully integrated with the overall program plans for PEO and NAVAIR managed acquisition programs in Acquisition Categories (ACAT) I through IV."[31] SETRs are important to the life of a program, since they provide an opportunity to provide an integrated technical input to the Program Manager on readiness of the program to move on to the next technical phase. All in all, the following 11 SETRs are outlined in this instruction:

- Initial Technical Review (ITR)
- Alternative Systems Review (ASR)
- System Requirements Review (SRR)
- System Functional Review (SFR)
- Preliminary Design Review (PDR)

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29 Electronic Industries Alliance/Naval Air Systems Command (NAVAIR), *NAVAIR Systems Engineering Guide*, DRAFT, 8 April 2002, p.2.

30 NAVAIR Instruction 4355.19B, *Systems Engineering Technical Review Process*, 25 June 2003, p. 1.

31 Ibid, p. 2.

- Critical Design Review (CDR)
- Test Readiness Review (TRR)
- Flight Readiness Review (FRR) (for airborne systems)
- System Verification Review/Production Readiness Review (SVR/PRR)
- Physical Configuration Review (PCR)
- Engineering Change Proposal Review (ECPR).

The SETRs can be tailored to the specific needs of a program and are in addition to Integrated Baseline Reviews (IBRs) and Operational Test Readiness Reviews (OTRRs). Additional information on the purpose, timing, entry criteria, planning, conduct of review, and exit criteria for each SETR may be found in NAVAIR's *Systems Engineering Technical Review Process Handbook*. Associated with this handbook, NAVAIR has also developed Program Risk Assessment Checklists corresponding to each of the SETRs.

c. Program/Project Risk Management

In the same timeframe as the introduction of the SETR process, NAVAIR also initiated NAVAIR Instruction 5000.21, *Program/Project Risk Management*. This instruction represents an effort to standardize the risk management process across NAVAIR, because risk represents the potential for schedule, cost, and performance variation. The policy therefore states: "All ACAT-designated, NAVAIR/PEO-managed aviation acquisition and in-service support programs shall establish, maintain and utilize an integrated risk management process."[32] In order to promote uniformity, "NAVAIR risk reporting shall present standard likelihood and consequence screening criteria, as well as the standard risk matrix."[33] Each risk description is to include a description of the root causal factors and the planned/proposed mitigation approach. The plotting of the accompanying risk matrix for a program plots "the PM's current assessment of the risk's probability of occurrence, and the estimated severity of its effect on the program if mitigation fails."[34]

2. Collaborative Engineering Environment

The Naval Collaborative Engineering Environment (NCEE) is an integrated digital engineering environment "based on both E-Business and E-Systems Engineering

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32 NAVAIR Instruction 5000.21, Program/Project Risk Management, 25 June 2003, p. 2.

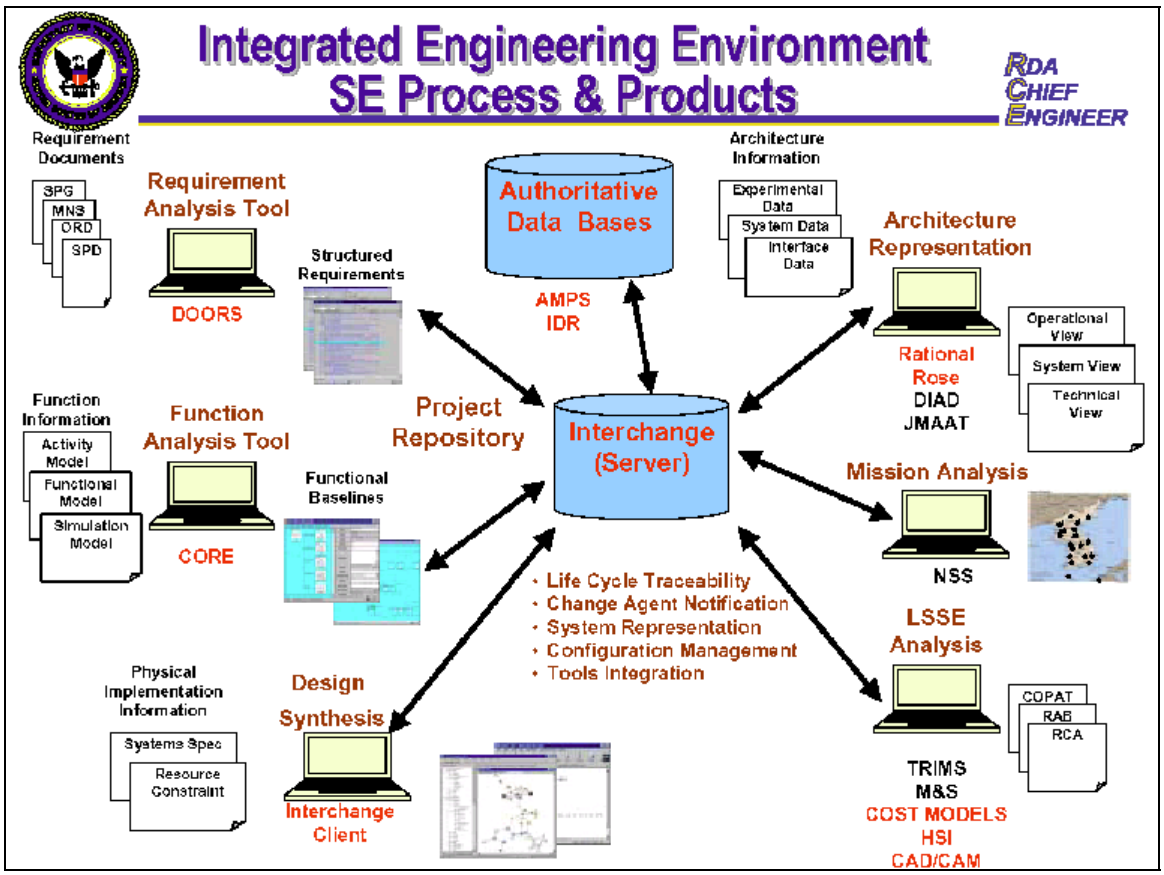
33 Ibid.

34 Ibid,. p. 3.

capabilities." It was developed to enhance "the cooperation and exchange of data, information, and knowledge among Naval stakeholders engaged in … activities directed toward assuring integrated and interoperable Naval force systems" and to enable "the integration and interoperability of Naval force systems across the spectrum of the Naval acquisition process."[35] Activities such as System Function Analysis, Requirements Management, Process Guidance, Organizational Design, Requirements Analysis, Human Performance Modeling, Physical Design Analysis, and Cost Analysis would take place within the NCEE.

The NCEE comprises three layers: Integrated Engineering Environment, Decision Support, and Interoperability Data Management and Analysis. Each layer includes different types of tools. For example, the Decision Support layer includes video teleconferencing and website applications, while the Integrated Engineering Environment includes applications and engineering tools such as DOORS, a requirements analysis tool; Rational Rose, an architecture representation tool; and CORE, a functional analysis tool (see Figure II-1, below, which is from Dr. Crisp's briefing).

[35] Dr. Harry E. Crisp, Director, RDA CHENG Naval CEE, "Naval Collaborative Engineering Environment," Briefing to the Conference on Systems Integration, Stevens Institute of Technology, Hoboken, NJ, 13 March 2003.



Source: Crisp, "Naval Collaborative Engineering Environment."

Figure II-1. NCEE Integrated Engineering Environment

3. Centers of Excellence

The Navy Manufacturing Technology (ManTech) program sponsors several Centers of Excellence (COEs). The following sections discuss those with relevance to systems engineering.

a. Best Manufacturing Practices Center of Excellence

The Best Manufacturing Practices Center of Excellence (BMPCOE), located at the University of Maryland in College Park, publishes best practices and guidelines. The Center also performs systems engineering analyses and risk management and assessment for various military projects.

b. National Center for Excellence in Metalworking Technology

The National Center for Excellence in Metalworking Technology (NCEMT), located in Johnstown, Pennsylvania, has state-of-the-art capabilities in advanced materials testing, process development and modeling, component design, concurrent

engineering, systems technology, simulation, and systems integration.[36] It is operated by the Concurrent Technologies Corporation (CTC).

c. National Defense Center for Environmental Excellence

The National Defense Center for Environmental Excellence (NDCEE) researches and develops recycling, recovery, and reuse systems and environmentally acceptable applications and systems that remove coatings from military, commercial, and space tools and equipment.[37] CTC also operates this center for the Navy.

4. United States Naval Academy

The Department of Weapons and Systems' bachelor of science in systems engineering emphasizes mathematical modeling, analysis, synthesis, control, and simulation. Midshipmen majoring in systems engineering take "Programming for Engineers," which teaches programming in C, as well as classes in statics, electrical engineering, computer methods (analog and digital), control systems (linear and advanced), and naval weapons systems. These are required courses focused on programming, integration, simulation, and design and are in addition to calculus, physics, chemistry, and mathematics course sequences and the general English, history, and naval science requirements. During their senior year, midshipmen take two sequences of two courses in any of several elective tracks. One elective sequence must be in the systems engineering group, made up of courses in information systems, control systems, computer engineering, and robotics. The other sequence should be in a non-systems engineering group, which includes tracks in environmental engineering, electrical engineering, mechanical dynamics, nuclear engineering, aerospace engineering, and astronautics engineering. Finally, there is a two-course capstone design project during the senior year.

5. Naval Postgraduate School

A master of science in systems engineering (for those holding an undergraduate degree in engineering) and a master of science in systems analysis (for those without) are offered at the Naval Postgraduate School (NPS). The 18-month program is directed at "unrestricted line officers" in the Navy, with preference given to those from the surface, subsurface, and aviation areas. Courses are distributed among technology, analysis, engineering, seminars, and Joint Professional Military Education. The technology courses

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[36] "Science and Technology–National Center for Excellence in Metalworking Technology," http://www.onr.navy.mil/sci_tech/industrial/bops/ncemt.htm.

[37] "NDCEE Capabilities Summary," http://www.ndcee.ctc.com/pdf/capsum.pdf.

focus on sensors, weapons, information systems, and networks. Analysis courses examine analysis, combat simulation, and modeling. Engineering courses emphasize systems architecture and design, software engineering, and human-factors engineering. Also required are classes on optimization, modeling, project management, statistics, and refresher mathematics courses. In addition, students must take six courses through the Navy War College that satisfy Phase 1 of Joint Professional Military Education—two classes in national security decision-making, three in joint military operations, and one in strategy and policy. A group project is also required.

An alliance being established between the NPS and AFIT is described earlier in Section II.C.2.

6. Wayne E. Meyer Institute of Systems Engineering

The Wayne E. Meyer Institute of Systems Engineering (Meyer Institute), similar to its predecessors, the Institute for Defense Systems Engineering and Analysis (IDSEA) and the Institute for Joint Warfare Analysis (IJWA), is located at NPS. The NPS has historically provided graduate-level coursework and programs in systems engineering theory and application. The vision of the Meyer Institute is "to provide unique graduate education and research that increases the knowledge and skills of military officers and the supporting civilian workforce in systems engineering and analysis and large-scale experimentation." The Meyer Institute is intended to improve upon and integrate existing NPS coursework and programs related to systems engineering, while also expanding its education and research capabilities. Nearly 20 professors, lecturers, and associates are presently associated with the Meyer Institute's education and research endeavors. A Board of Advisors, consisting of six high-ranking (Admiral or General-level) Naval and Marine Corps officers and two professors from academia, assist the Meyer Institute's director in setting priorities for research and curricula expansion.

7. The Systems Research Center

The Systems Research Center (SRC) is located at the Virginia Polytechnic Institute and State University (Virginia Tech) in Blacksburg, Virginia. Its mission statement is—

> To conduct research and exploratory development in computing support systems of interest to the Navy, other governmental agencies, or private industry. The focus is on systems solutions to problems. The scope of analysis can range from algorithms for ballistics computation to the

architecture for computer communications in support of a Battle Group or Theater Operations.[38]

The charter for the SRC was approved in the spring of 1984 after a series of meetings involving several key Navy personnel. The director of the center reports to the vice provost for research and graduate studies. An advisory board is composed of one representative each from the Naval Sea Systems Command (NAVSEA) and the Naval Surface Warfare Center, Dahlgren Division (NSWCDD), and two representatives from the Virginia Polytechnic Institute (VPI) and the State University (Virginia Tech). For research there are both a resident senior scientist and a senior associate with a host of collaborative faculty from universities all over the United States to support them. Five other personnel at the Center serve in administrative functions for business or computer systems.

8. Academic Relationship with Old Dominion University

The U. S. Navy has had a continued collaboration with Old Dominion University (ODU) in Norfolk, Virginia. Included in this collaboration is the establishment of the National Center for System of Systems Engineering (NCSOSE) and the ability of Navy officers stationed at sea to earn Master's degrees through the use of an ODU CD-ROM. ODU has also recently added a degree program in systems engineering to its long-standing Engineering Management Program.

a. National Centers for Systems of Systems Engineering

The National Centers for Systems of Systems Engineering (NCSOSE) was established at Old Dominion University in 2002. The NCSOSE's primary mission is to "advance the body of knowledge and state-of-the-art relating to engineering complex system of systems."[39] Its vision is that it will comprise various "independent, nonprofit, engineering research and application organizations, government entities, and universities."[40] However, it is currently only funded by the Navy in the application of Seaport Security and Force Protection, and the team only comprises Old Dominion University and two Navy Centers of Excellence—Concurrent Technologies, Inc. and Best Manufacturing Practices.

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38 http://www.src.vt.edu/SRCWebSite/mission.htm.

39 "Center Overview," National Centers for Systems of Systems Engineering website, http://www.eng.odu.edu/ncose/about.htm.

40 Ibid.

b. Master of Engineering Management Program for Naval Officers

Because many of the Navy's nuclear-qualified officers are stationed on submarines that are often submerged, they cannot receive ODU's standard distance learning broadcast signal. However, Admiral John Grossenbacher, commander of Naval Submarine Forces, has said "We need every tool we can to deliver education to them in the most efficient way possible, and wherever and whenever." [41] Thus, ODU designed a program for active duty Navy and designated personnel, which includes 18 (and soon to be 19) of the 30 credit hours available for delivery via CD-ROM format for those who are determined to be eligible.[42] The courses for the Master of Engineering Management program are available to students serving at sea through the Navy College Program for Afloat College Education.

c. Navy College Program for Afloat College Education

A master of engineering management degree is available from Old Dominion University via distance learning in conjunction with the Navy College Program for Afloat College Education (NCPACE). The program is aimed at nuclear officers in the Navy stationed aboard submarines. Ten classes are required for completion of the degree; six are available on CD-ROM. The courses focus on cost estimation/financial analysis, systems design and analysis, operations research, program management, and logistics and supply chain management.

9. Systems Engineering Certificate with Stevens Institute of Technology

The Stevens Institute of Technology's graduate certificate in systems engineering is offered at the Naval Air Systems Command (NAVAIR) installation in Lakehurst, New Jersey. Both NAVAIR employees and non-NAVAIR employees can enroll in this program. An undergraduate degree in engineering or a related field, along with a grade point average of 3.0 or better, are required for admission. In addition, outstanding applicants in disciplines other than engineering may be conditionally admitted subject to the satisfactory completion of several "ramp" courses or the introductory courses within the program. The program consists of 4 courses, for a total of 12 credits. The core

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41 Richard S. Koonce, "Navy Officers Earn Degrees in New Program," *Norfolk Virginia-Pilot*, 16 December 2002.

42 "Master of Engineering Management Program (Ashore)," http://www.dl.odu.edu/partnerships/mem/ashore/index.html.

courses are "Operational Effectiveness and Life-Cycle Analysis," "Systems Architecture and Design," "Simulation and Modeling," and "Project Management of Complex Systems."

E. MARINE CORPS

This section summarizes various systems engineering-related programs, efforts, and activities already undertaken by the U.S. Marine Corps.

1. Marine Corps Systems Command

Located in Quantico, Virginia, the Marine Corps Systems Command (MARCORSYSCOM) is involved in acquisition, life-cycle management, and engineering of combat and support systems. Several project groups fall under MARCORSYSCOM's purview:

- Information Systems and Infrastructure
- Battlespace Management and Air Defense Systems (BMADS)
- Infantry Weapons Systems
- Armor and Fire Support Systems
- Ground Transportation and Engineer Systems
- Combat Equipment and Support Systems.

In addition, there is an Infantry Systems Integration Support Group. Of the product groups, only BMADS has a section with specific responsibility for systems engineering, the Systems Engineering Team, which advises the BMADS director and engages in a "phased, evolutionary systems engineering strategy in sustaining, modifying, developing, and fielding integrated Command, Control, Communications, and Computer and Air Defense weapons systems."[43]

2. Marine Corps Tactical Systems Support Authority

The Marine Corps Tactical Systems Support Authority, part of MARCORSYSCOM, is based at Camp Pendleton, California. Its Systems Engineering and Integration Division performs "interoperability and integration assessments of Command, Control, Computer, Communications, Intelligence, Reconnaissance, and

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[43] BMADS Systems Engineering Team, http://www.marcorsyscom.usmc.mil/sites/maccs/pmbm/set/sysengteam.asp.

Surveillance systems" and "operates and maintains" the Systems Integration Environment, which is a test facility.[44] It also operates the Marine Corps Network Design Facility.

F. ARMY

This section summarizes various systems engineering-related programs, efforts, and activities already undertaken by the U.S. Army.

1. Army Systems Engineering Office

Based on a 1994 Army Science Board study, "the Army Acquisition Executive (AAE)/Vice Chief of Staff, Army, issued a tasking memorandum that established responsibilities for the establishment, maintenance, coordination and enforcement of the Army's Information Systems technical and operational architecture components."[45] The Army Systems Engineering Office (ASEO) was established to provide technical support. "The mission of the ASEO is to provide technical support to the Director, Communications-Electronics Command (CECOM) Research, Development, and Engineering Center (RDEC) in his role as the Army's Systems Engineer and to provide general support to Army organizations regarding the interpretation of the Joint Technical Architecture–Army (JTA-A) mandates."[46] In addition the ASEO supports the Army's representative to the JTA community, the Army's Director of Information Systems for Command, Control, Communications, and Computers (DISC4). The ASEO's two primary responsibilities include working to ensure JTA-A compliance and JTA/JTA-A standards identification.

2. Corps of Engineers Corporate Systems Engineering Environment

The mission of the Corporate Systems Engineering Environment (CSEE) is to provide an environment where functional managers, program managers, and material developers can design, develop, maintain, and test their systems using repeatable and

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44 "MTCSSA Internet,"http://www.mctssa.usmc.mil/SEI/seisd.asp.

45 "Our History," Army Systems Engineering Office website, http://www.monmouth.army.mil/cecom/rdec/ aseo/history.html.

46 "Our Mission," Army Systems Engineering Office website, http://www.monmout.army.mil/cecom/rdec/aseo.

standard processes, thus reducing and incrementally eliminating systems malfunctions due to lack of systems integration. The objectives of the CSEE are to—[47]

- Deploy quality and coherent U. S. Army Corps of Engineers (USACE) Automated Information Systems (AIS)
- Support integration and interoperable functions between USACE AIS
- Reduce costs included in deploying USACE AIS
- Promote repeatable processes in developing, supporting, and maintaining USACE AIS

The CSEE falls under the purview of the Information Technology Services Division of the USACE and, accordingly, is totally geared toward information systems. It also has a Systems Engineering Process Improvement Plan that supports the Information System Modernization Program.

3. United States Military Academy

The United States Military Academy at West Point, New York, offers a Bachelor of Science in systems engineering. Cadets must take a five-course core sequence in systems engineering, followed by electives in various areas. The systems engineering core focuses on modeling, simulation, analysis, and engineering and includes a research seminar. One course in simulation, one math elective, and an elective drawn from the fields of electrical engineering, mechanical engineering, and systems engineering are also required.[48]

G. DEFENSE ADVANCED RESEARCH PROJECTS AGENCY

The Defense Advanced Research Projects Agency (DARPA) sponsors the Mid-Atlantic Regional Consortium for Advanced Vehicles (MARCAV) consortium through its Electric/Hybrid Vehicle Program.[49] Design, manufacturing, testing and evaluation support, along with systems engineering and design and optimization of military vehicles, are MARCAV's main thrusts. The MARCAV consortium is operated by the Concurrent Technologies Corporation (CTC).

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47 Corps of Engineers Corporate Systems Engineering Environment (CSEE) Home Page, http://www.usace.army.mil/ci/esee/esee.html.

48 Further information on course requirements and focus is unavailable. Engineering electives from outside systems engineering focus on computer-aided design, computer logic, organization behavior, and human-computer interaction. Electives in systems engineering focus on decision support systems and modeling.

49 "Welcome to MARCAV," http://www.marcav.ctc.com.

III. EFFORTS IN OTHER GOVERNMENT AGENCIES

This chapter provides information on the activities related to systems engineering within government agencies other than the DoD.

A. DEPARTMENT OF ENERGY

The Department of Energy (DoE) is involved in many systems engineering activities, through both its National Nuclear Security Administration (NNSA) and its National Laboratories.

1. National Nuclear Security Administration

The National Nuclear Security Administration (NNSA) is a semi-autonomous agency of the DoE. Within its Defense Programs Office, the Office of Simulation and Computer Science "provides the enabling computer and simulation technologies needed to design and implement Stockpile Stewardship Program (SSP) simulations."[50] One of the four programs to accomplish this is the Project Solving Environment (PSE). The PSE is geared towards refining and improving software process improvement activities across the Lawrence Livermore, Sandia, and Los Alamos National Laboratories. The focus of the PSE project is software quality engineering and systems engineering practices, and the labs' participation "includes helping to collect, validate, and manage user requirements, to develop accurate usage models and architectures for PSE as well as Simulation and Computer Sciences."[51]

2. National Laboratories

a. Sandia National Laboratory

Sandia National Laboratory takes a four-team approach to implementing systems engineering: Process, Education, Tools, and Industry/University. The Process team develops and documents systems engineering processes, while the Education team

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50 Simulation and Computer Science, http://www.nasa.doe.gov/asc/SimCompSci.htm..

51 ASCI Tri-Lab PSE Software Quality and Systems Engineering Overview, http://www.llnl.gov/asci/pse_trilab/software_quality.html; and ASCI Tri-Lab PSE Software Quality and Systems Engineering Project Activities,; http://www.llnl.gov/asci/pse_trilab/software_quality_activities.html.

provides systems engineering training and information to Sandia personnel. Members of the Tools team are engaged in creating an effective systems engineering environment; those on the Industry/University team work with industry and academia to improve systems engineering skills. In addition, Sandia instituted a systems engineering upgrade effort in 1993 "to improve the skills of the systems engineers and to incorporate new ideas and advances from recent developments in the systems engineering field."[52]

Sandia departments and centers engage in systems engineering in a number of ways. The Systems Engineering Department, located in Livermore, California, focuses primarily on the development, integration, and operations of the Extreme Ultraviolet Engineering Test Stand, as well as on systems control and software. This department also works on developing engineering and control for precision engineering programs, applications, and hydrogen projects.[53] The Infrastructure and Information Systems Center has "extensive expertise in developing tools and techniques to integrate systems of systems."[54]

Sandia's participation in the PSE is in the area of "expanding and codifying the use of software quality processes" for requirements management, software configuration management, and project planning and tracking.[55]

b. Los Alamos National Laboratory

Two divisions of the Los Alamos National Laboratory, based in Los Alamos, New Mexico, are engaged in systems engineering work. The Stockpile Complex Modeling and Analysis Division (also known as "D-2") provides systems engineering support "to define, manage, and evaluate critical program and project interfaces," while the Systems and Integration Division (also known as "D-3") "develops methods of systems engineering and integration in support of Los Alamos and national programs in

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52 Sandia National Laboratories—Albuquerque, New Mexico: Systems Engineering, http://www.bmpcoe.org/bestpractices/external/sandi/sandi_85.html.

53 Systems Engineering Department–8731, http://www.ca.sandia.gov/Materials&EngineeringSciences/SysEng/syseng1.html.

54 Information Systems Engineering Applications, http://www.sandia.gov/organization/div6000/ctr6500/isea.html.

55 Ibid.

defense, energy, and advanced technology."[56] Los Alamos also participates in the PSE project. Its contribution is in the areas of life-cycle and software development procedures.

c. Lawrence Livermore National Laboratory

The Detection and Defense Group of the Lawrence Livermore National Laboratory in Livermore, California, counts systems engineering as one of its core expertise areas that are applied to several multidisciplinary projects. Lawrence Livermore is also involved in the PSE, in the areas of software configuration management, software quality assurance, requirements management, peer reviews, and project planning, tracking, and engineering.

d. Oak Ridge National Laboratory

The Nuclear Science and Technology Program of Oak Ridge National Laboratory, based in Oak Ridge, Tennessee, administers a Systems Engineering Analysis Educational Program. This program is an evolving initiative aimed at full-time college and university faculty and college and university students who are U.S. citizens. Participants engage in simulation and modeling, risk analyses, and research and development management for uses of depleted uranium. A varying number of awards are available each year, and a stipend and some travel reimbursement are offered.

e. Pacific Northwest Laboratory

Pacific Northwest National Laboratory, located in Richland, Washington State, has a Defense Systems Engineering product line.

f. Lawrence Berkeley National Laboratory

The Systems Engineering Department of Lawrence Berkeley National Laboratory in Berkeley, California, sponsors a "series of tutorials to provide the…staff with the fundamentals of systems engineering."[57] In this series, systems engineering experts from the International Council on Systems Engineering (INCOSE) and elsewhere come to Lawrence Berkeley to present lectures, workshops, and case studies on such topics as decision analysis and risk management, systems and software engineering, the art of systems architecting, and the engineering of complex systems.

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[56] D-2: Stockpile Complex Modeling and Analysis, http://www.lanl.gov/orgs/d/d2/projects.shtml; Systems Engineering and Integration D-3, http://www.lanl.gov/orgs/d/d3.

[57] Systems Engineering Training and Education, http://engineering.lbl.gov/sy/training.htm.

In addition to the tutorials, the Department has an informal systems engineering discussion group.

g. Idaho National Engineering and Environmental Laboratory

The Systems/Integration Group of the Idaho National Engineering and Environmental Laboratory, which is located in Idaho Falls, has Systems Science Research as a focus area.

B. NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

The Office of the Chief Engineer at the National Aeronautics and Space Administration (NASA) has instituted the Systems Engineering Excellence Initiative across all the NASA Centers to improve NASA's systems engineering capability and provide a common Framework to provide consistency in the application of systems engineering at all levels within NASA.

The Office of the Chief Engineer promotes the following vision and mission for systems engineering at NASA.

> *Vision*: A premier systems engineering capability widely recognized for its leadership and expertise in the engineering of systems and subsystems to enable NASA to provide leading edge aerospace research, products, and services.
>
> *Mission:* Develop and implement the Systems Engineering Framework and promote the environment for excellence and the revolutionary advancement of the system engineering capability to anticipate and meet the needs of NASA Programs and Projects.

The Systems Engineering Excellence Initiative's goals are to—

- Ensure continuous improvement of the NASA engineering workforce through relevant education, training, and work experiences
- Ensure sound and effective *systems* engineering as well as discipline-specific engineering
- Develop and implement the Advanced Engineering Infrastructure to further enable the achievement of enterprise goals
- Provide value-added cross-enterprise products and services that enable the infusion of technology, knowledge, and capabilities to enable innovation in engineering and push the state of the art
- Increase participation, membership, and leadership in recognized national and international engineering organizations

The initiative has also recognized the need for a common lexicon of systems engineering terminology and definitions to enhance communication and collaboration among engineering teams across NASA and with their external partners and customers.

1. Organization

To manage this Initiative, NASA has established the Systems Engineering Working Group to plan, develop, and execute the Framework, as well as to coordinate the Framework products within the NASA Centers. NASA has also established the Engineering Management Board to provide project oversight and approvals. Each Center has its own systems engineering organization tied into the overall initiative.

2. Framework

The Framework itself will provide—

- A culture based on rapid prototyping, modeling, and simulation capability for development of multiple and diverse designs
- Experienced and well-trained engineers in application of process, tools, methodology, and customer relationship and interaction
- Continuous improvement through self-assessment at the personal and organizational levels[58]

3. Advanced Engineering Environments

To ensure the success of future aerospace systems, NASA has recognized a need for improved synthesis and collaboration between a diverse set of distributed assets and activities for the purposes of advanced engineering. More specifically, NASA has sought to address this through advanced engineering environments (AEEs). "AEEs would incorporate advanced computational communications, and networking facilities and tools to create integrated virtual and distributed computer-based environments linking researchers, technologists, designers, manufacturers, suppliers and customers."[59]

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[58] Steve Kapurch, *NASA Systems Engineering Excellence Initiative*, Briefing, Systems Engineering Program Executive Officer, Office of the Chief Engineer, June 2002.

[59] Committee on Advanced Engineering Environments, *Advanced Engineering Environments: Achieving the Vision, Phase 1*, http://books.nap.edu/html/adv_eng_env/index.html.

Established in January 2001, NASA's Langley Research Center serves as the home for the Center for Advanced Engineering Environments, which is administered by Old Dominion University.[60] This Center's goals are as follows:

- To perform research on the use of collaborative and distributed means to synthesize future systems
- To create technical and strategic approaches to support advanced learning environments
- To be a leader within the research community at large
- To assist in determining research paths to support future space and aeronautical missions
- To assist in disseminating research results to industry in order and to improve awareness of collaborative and distributed tools, approaches, and activities[61]

a. Systems Engineering Modeling and Design Analysis Laboratory

Another NASA-related advanced engineering activity is the Systems Engineering Modeling and Design Analysis (SEMDA) Laboratory. Located at Lockheed Martin Space Operations, SEMDA Lab enables coordination of systems engineering and analysis activities with the Johnson Space Center Systems Engineering Office (EA4), the International Space Station (ISS) Mission Integration (OM), Resource Management Analysis and Integration Team (RMAIT), and the Exploration Office (EX). The Lab's main focus is the development and analysis of CAD solid models for the ISS and its component parts. A geometry database for the ISS captures the data collected via its CAD model work, which can be used for other assessment and analysis purposes, for example, Assembly Clearance Analysis for ISS Mission Integration and the ISS Vehicle Integrated Performance and Resources (VIPeR) Team. [62]

b. National Research Council Study

NASA has undertaken projects with both short- and long-term goals related to the use of advanced engineering activities and the appropriate environments in which to implement them. The NASA Chief Engineer and Chief Technologist have asked for a study of this NASA advanced engineering environment work, but within a broader

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60 "Mission Statement," Old Dominion University, Center for Advanced Engineering Environments website, http://oduaee-www.larc.nasa.gov/mission.html.

61 "Information Guide to Research and Education Programs for Year 2002/2003— Center for Advanced Engineering Environments," NASA Langley Research Center website, http://edu.larc.nasa.gov/InfoGuide/faculty_postdoctural_advnc.html.

62 "About SEMDA Lab," Lockheed Martin—Science, Engineering, Analysis, and Test Contract website, wysiwyg://13/http://seat1.jsc.nasa.gov/semda/doks/semda.html.

context, by the National Research Council and the National Academy of Engineering.[63] This study, conducted by the Advanced Engineering Environments Committee, is divided into two phases, the first focusing out 5 years and the second looking out farther to 15 years. During Phase I, the committee summarized the ideal AEE in the following vision: "It should create an environment that allows organizations to introduce innovation and manage complexity with unprecedented effectiveness in terms of time, cost, and labor throughout the life cycle of products and missions."[64] The committee recommended the creation of a partnership, based on the AEE concept and spanning government, industry, and academia, to begin with a focus on NASA and its interactions with external bodies.

Phase II of this study focused on the long-term potential of AEE technologies and systems and reaffirmed Phase I's call for a collaboration among government, industry, and academia on achiev[ing] the AEE vision. It also recommended that AEEs be designed for compatibility with Internet-related technologies and applications. In addition, the study called for a change in education and training at both the undergraduate and graduate levels in order to create an AEE-qualified workforce. [65]

C. FEDERAL AVIATION ADMINISTRATION

The Federal Aviation Administration (FAA) is involved in systems engineering at three levels: National Aerospace System (NAS) Architecture, Investment Analyses, and implementation of systems engineering. The NAS Architecture looks at the overall "system of systems" of the NAS. Investment Analyses and implementation of systems engineering look at, respectively, at the sources of solutions and the implementation of those solutions.

The NAS System Engineering and Analysis Division oversees technical, engineering, and analysis work at the NAS level. A component of the division is the Systems Engineering Group, which "provides NAS-level technical engineering, analysis, and guidance support to the Office of NAS Architecture and System Engineering, and other NAS systems engineering and requirements determination organizations."[66] It also develops the overall systems engineering strategy, defines systems architecture design,

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63 Advanced Engineering Environments—Achieving the Vision: Phase I, http://books.nap.edu/html/adv_eng_env/index.html.

64 Ibid.

65 National Academy of Engineering, *Design in the New Millennium--Advanced Engineering Environments, Phase II,* (Washington, DC: National Academy Press, 2000), vii; 1.

66 NAS System Engineering Group website, http://acb210/tc/faa/gov.

analyzes systems requirements, develops software architecture/detailed designs, develops and tests software code, integrates software, and conducts design qualification tests. Implementation is done through the Integration Product Team.

The FAA also participated in the development of the Capability Maturity Model Integration–Systems Engineering/Software Engineering/Integrated Product and Process Development/Supplier Sourcing (CMMI–SE/SW/IPPD/SS). The FAA has its own capability model called the iCMM.

D. NATIONAL SCIENCE FOUNDATION

The National Science Foundation (NSF) Directorate for Engineering—

> … promotes the progress of engineering in the United States in order to enable the Nation's capacity to perform. Its investments in engineering research and education aim to build and strengthen a national capacity for innovation that can lead over time to the creation of new shared wealth and a better quality of life.[67]

The NSF, however, does not recognize systems engineering as a separate engineering discipline for the purposes of collecting engineering academic and workforce data or funding research. Systems engineering in NSF data is lumped into the "Other Engineering" category. Although systems engineering is not a recognized area within the NSF, the Engineering Directorate is divided into the following areas, many of which have "Systems" in their title:

- Bioengineering and Environmental Systems
- Civil and Mechanical Systems
- Chemical and Transport Systems
- Design, Manufacture, and Industrial Innovation
- Electrical and Communications Systems
- Engineering Education and Centers

Engineering Education and Centers covers the Engineering Research Centers (ERCs) program. NSF created the ERCs Program in 1985 "to develop a government-industry-university partnership to strengthen the competitive position of U.S. firms in world trade and change the culture of engineering research and education in the U.S."[68] There are currently numerous ERCs across the country. The NSF funds two systems-

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67 National Science Foundation website, http://www.nsf.gov/home/eng.

68 *The Engineering Research Centers (ERC) Program: An Assessment of Benefits and Outcomes*, Engineering Education and Centers Division, Directorate for Engineering, National Science Foundation, December 1997.

related centers under the ERC program, the Institute for Complex Engineered Systems (ICES) and the Institute for Systems Research (ISR).

1. Institute for Complex Engineered Systems (ICES)

The Institute for Complex Engineered Systems (ICES) represents a multidisciplinary initiative within the College of Engineering's Carnegie Institute of Technology (CIT), located at Carnegie Mellon University (CMU) in Pittsburgh, Pennsylvania. "ICES seeds and fosters multidisciplinary research, education and outreach that is related to the design and operation of complex engineered systems."[69] The core competencies of the ICES include education, an Engineering Design Research Center (EDRC), and Micro Electro-Mechanical Systems (MEMS) and Mechatronics. Over 200 professors, staff, and students (undergraduate and graduate) across seven different CMU colleges work on ICES projects. Originally established and funded by the NSF in 1985, the ICES became a self-sustaining ERC in 1997. The ICES is currently supported by internal investments from the office of the Provost and the Dean of the College of Engineering at CMU, various federal agencies, the state of Pennsylvania, and industry partners.

2. Institute for Systems Research (ISR)

The Institute for Systems Research (ISR) began in 1985 as a University of Maryland and Harvard University joint venture that was one of the NSF's six original ERCs. The ISR's mission is to develop, demonstrate, and teach methodologies for the solution of complex, heterogeneous, and dynamic problems of engineering technology and systems.[70] The emphases of ISR's research and education efforts include global communications systems, sensor-actuator networks, next-generation product realization systems, societal infrastructure systems, and interdisciplinary systems education. More than 50 professors and 300 students are associated with and participate in the ISR's collaborative research and teaching endeavors. The state of Maryland designated the ISR as a permanent institute of the University of Maryland in 1992 and it has been a self-sustaining ERC since 1997.

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69 Institute for Complex Engineered Systems website, http://www.ices.cmu.edu/mission.html.

70 The Institute for Systems Research, General Information, www.isr.umd.edu.

E. NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

The Manufacturing Engineering Laboratory at the National Institute of Standards and Technology (NIST) in Gaithersburg, Maryland, includes, among its research areas, (1) Interoperability and Integration and (2) Simulation, Visualization and Modeling. Both of these areas are important to systems engineering since they address such issues as interfacing and networking, open architecture control, product data standards including the Standard for the Exchange of Product Data (STEP), conformance testing, simulation architectures and interfaces, distributed simulation standards, and neutral models and prototypes. More information on the product data exchange standards provided in Section V.C.

IV. ASSOCIATIONS

Various associations are either devoted in whole to systems engineering or have divisions or committees that conduct activities related to systems engineering. These associations, divisions, and committees are described in this chapter.

A. INTERNATIONAL COUNCIL ON SYSTEMS ENGINEERING

The International Council on Systems Engineering (INCOSE) is a professional organization for industry, government, and academic professionals with knowledge and experience in systems engineering. INCOSE is an international authoritative body promoting the interdisciplinary approach and means to enable the realization of successful systems.[71] In fostering the definition, understanding, and practice of systems engineering, INCOSE operates with the following goals: [72]

- Promote collaboration in systems engineering education and research through the Systems Engineering Center of Excellence (SECOE)
- Ensure the establishment of professional standards for integrity and the practice of systems engineering
- Augment the professional status of systems engineers
- Promote governmental and industrial support for research and educational programs that will improve the systems engineering process and its practice
- Work with industry, academia, and government to provide a focal point for the dissemination of systems engineering knowledge

In addition to these overarching goals, INCOSE's Corporate Advisory Board, Technical Board, and Member Board worked in conjunction with other project leads to formulate INCOSE's "Top 5" initiatives for 2004. These initiatives are as follows:[73]

- Complete the classification of all existing INCOSE products and make them available to members on the Web
- Implement the *Guide to the Systems Engineering Body of Knowledge* and populate it

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71 INCOSE website, http://www.incose.org, 29 November 2000.

72 "Welcome to INCOSE!—Missions, Goals, and Objectives," INCOSE website, http://www.incose.org/intro.html, 26 November 2001.

73 Email from Valerie Gundrum, "Key Messages from the Portland International Workshop," 9 February 2004.

- Complete the INCOSE Technical Vision of the future of systems engineering
- Revise the *Systems Engineering Handbook* to version 3
- Implement the systems engineering certification program

In looking forward, INCOSE also has established its vision for 2006 and beyond, titled "Agenda 2006." This agenda consists of three key themes: [74]

- High value products and services for INCOSE (the prerequisites)
- Outreach, outreach, outreach! (the enablers)
- Organizational development (the engine)

1. Organization

To accomplish these goals, INCOSE is organized into the standard executive and administrative committees of an international membership organization. In addition, INCOSE has a Corporate Advisory Board (CAB), which provides guidance and recommendations from its industry members for INCOSE products and services.

The INCOSE Technical Board is the strategic planning and management body for the technical program of INCOSE. It is expected to involve the INCOSE membership and create liaisons with industry, academia, and government to:

- Provide and disseminate systems engineering knowledge and develop products in systems engineering applications, systems engineering management, measurement, modeling and tools, processes and methods
- Examine systems engineering tools, techniques, and processes among all Technical Committees (TCs) and within application domains
- Lead the development of systems engineering wherever possible through its activities and products

Technical Committees under the Technical Board include Education and Research, Modeling and Tools, Processes and Improvement, Systems Engineering Applications, Systems Engineering Initiatives, Systems Engineering Management, and Standards. Each of the Technical Committees has a number of Working Groups under it.

INCOSE awards certain individuals with the honor of being an INCOSE Fellow. This award was created in 1998, and today there are 21 individuals so honored. Fellows are defined as—

> … individuals with a significant history of systems engineering achievement in industry, government or academia. Of course, the key factor is in the quality of the recipient's work in systems engineering. As

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[74] Ibid.

> an academic, this would be someone who has pushed the theory, written great teaching material or simply acted as a marvelous teacher for a string of successful systems engineers. A Fellow from industry would be expected to have made a real difference and a contribution to systems engineering practice—for example, by intellectually leading the development of a string of ground-breaking products. Those in government would be expected to have contributed significantly to acquisition-related efforts.[75]

INCOSE has an Academic Council made up of representatives from the principal universities that teach systems engineering at the masters and doctorate levels.

In addition, INCOSE recently established a new program office in order to better support its "Top 5" initiatives. This program office "will also ensure the coordination of interrelated projects such as certification, the *Systems Engineering Handbook* version 3, and the *Guide to Systems Engineering Body of Knowledge*."[76]

2. Services, Projects, and Products

a. INCOSE Website

INCOSE has recently launched its new public website, located at www.incose.org. The new site is designed to (i) provide up-to-date [systems engineering] information to better engage INCOSE members and encourage them to participate in leadership chapter and/or technical activities; (ii) highlight [systems engineering] achievements and products to INCOSE members, non-member [systems engineering] practitioners, others in the PM/engineering community, and the general public, and (iii) encourage non-member [systems engineers] to join INCOSE by demonstrating the value of membership.[77] A new INCOSE Connect site was scheduled for launch on 1 August 2004 to provide the various INCOSE working bodies with collaborative workspaces that can be customized.

b. Systems Engineering Center of Excellence

The Systems Engineering Center of Excellence is a virtual collaboration of academic and industry researchers to advance the state of knowledge about systems engineering. Participants are universities, organizations, and individuals with the desire to

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75 http://www.incose.org/fellows.html.

76 "Key Messages from the 2004 International Symposium in Toulouse," Email to INCOSE Members from Valerie Gundrum, 9 July 2004.

77 Ibid.

foster empirical and theoretical research into the engineering of complex systems. The INCOSE website is the center of the SECOE; it provides information and electronic connectivity for collaboration.

The SECOE is also a separate arm of INCOSE for contracted research. It receives guidance from the INCOSE Education and Research Technical Committee. Administration of SECOE is contracted out by INCOSE as a part of each research contract. In addition to research coordination, the SECOE administration is responsible for the development and encouragement of research funding.[78] One is to gather statistical information to quantify the value of systems engineering. The results will allow managers to select intelligently the degree of program risk by selecting the level of systems engineering investment.

c. Accreditation Board for Engineering and Technology

A project is underway whereby the Accreditation Board for Engineering and Technology (ABET) will accredit systems engineering programs in academia using INCOSE-sponsored Systems Engineering Program Criteria. (See more about ABET in Section VI.A.)

d. Systems Engineering Handbook

The *Systems Engineering Handbook* was developed by the Systems Engineering Handbook Working Group under the Process and Improvement Technical Committee. The Handbook is issued as an INCOSE Information Product. It is a "how-to" guide for all engineers that covers implementation steps, methodologies and tools, examples, metrics; and references. It conforms to both ANSI/EIA-632 and EIA-731 standards (see Sections IV.C, V.A.2, and V.B.1). The handbook gives a systems engineering overview that includes basic definitions, the role of systems engineers, and a discussion of the systems engineering process. The system engineering process activities are described within the larger project and product life cycle context in which they are performed. The system engineering process activities are divided into the areas of defining needs, technical management, system design, product realization, technical analysis and evaluation, product control, process control, and system post-implementation support.

An announcement was made in June 2004 that a new version (version 2a) of the *Systems Engineering Handbook* had been released. Through this new version "INCOSE

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78 http://www.secoe.org/intro.htm.

has greatly improved the handbook by reducing the redundancy, improving consistency, and removing US and DoD-specific terminology while retaining all material that supports the Systems Engineering Certification exam. Version 2a of the handbook provides a description of the key process activities performed by systems engineers, the purpose for each process activity, what needs to be done, and how it can be done."[79]

One of the "Top 5" initiatives for 2004 includes the development of version 3 of the *Systems Engineering Handbook*. A technical project plan, including input from the Board of Directors, Technical Board, Member Board, and the Corporate Advisory Board, is not complete. The steering group in charge of this next version of the Handbook will send out an annotated outline for review prior to the further development of each section and has as a goal "to have the Technical Board draft ready by the 2005 International Workshop with release at the 2005 International Symposium."[80]

e. Systems Engineering Certification

The Systems Engineering Certification Working Group was chartered under the Education and Research Technical Committee. INCOSE has contracted with Prometrics, which runs 6,000 testing centers for nonprofit organizations, to develop a Systems Engineering Certification test. The source for the development of this certification test is the INCOSE *Systems Engineering Handbook*. The envisioned Systems Engineering Certification will complement ABET accreditation

A beta test of 20–50 participants was completed around the time of the INCOSE Symposium in Washington, D.C., in July 2003. In March 2004 the INCOSE Board of Directors formally approved a "formal method for recognizing the knowledge and experience of systems engineers. The title of the baseline recognition of personal certification is *Certified Systems Engineering Professional*."[81] Through this certification, INCOSE warrants that an individual has attained a certain level of competency in a set of systems engineering skills as demonstrated through a minimum of 5 years of systems engineering technical experience, a bachelor's degree or equivalent in a technical field from an accredited university, the successful completion of a systems engineering knowledge examination, and a minimum of three technical references. One's certification

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79 Email from Valerie Gundrum, "INCOSE News and Notes," 5 June 2004.

80 Email from Valerie Gundrum, "Key Messages from the March 2004 Board of Directors Meeting," 5 April 2004.

81 "Certification," INCOSE website, http://www.incose.org/educationcareers/certification, 13 June 2004.

is valid for 3 years from the date of award and may be renewed in 3-year intervals. Those individuals who passed the exam during the 2003 beta test have been encouraged to submit their application package for certification, and the INCOSE certification team further expects to accept new applications at the end of 2004. The ultimate plan and architecture for the Systems Engineering Certification Program envisions "five categories—a foundation level and four equal but unique advanced levels that may be achieved after the foundation level has been attained."[82] These future advanced certification levels are as follows: Systems Engineering Management; Systems Engineering Specialist; Systems Engineering Enterprise Processes; and Systems Engineering Fellow.

f. Systems Engineering Body of Knowledge

A Systems Engineering Body of Knowledge (SEBoK) Working Group formed under the Education and Research Technical Committee developed the SEBoK using the basic tenet that no single source can encompass the SEBoK. Rather, INCOSE says, "the knowledge is dispersed among INCOSE and non-INCOSE practitioners and is as varied as our projects and interests." The SEBoK, therefore, is not a specific, concrete entity, but rather the sum of the systems engineering knowledge and experience that exists among the systems engineering community at large. The SEBoK includes processes, lessons learned, products, and standards which have been developed for many decades.

A *Guide to the SEBoK* (G2SEBoK) was developed which "does not simply "warehouse" knowledge, but includes dynamic relationships within the knowledge provided, and allows a user to access the products, organizational elements, and people who have both explicit and tacit knowledge." The strategy for the G2SEBoK is twofold: first, identify the components of the SEBoK in order to "define systems engineering in the broadest of terms;" and second, "use the accepted text as a framework to develop a method for 'connecting' information." The initial text-based version of the G2SEBoK was published in the April 2002 edition of *INCOSE INSIGHT*, but ultimately the goal is for this to exist as a Web-enabled tool.

g. Systems Architecting and Measurement Tools

The INCOSE Tools Database Working Group developed System Architecting and Measurement tool vendor surveys and summaries and posted them to their website. This

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82 "Possible Future Levels of Certification," INCOSE website, http://www.incose.org/educationcareers/certification/levels.aspx, 13 June 2004.

effort encompassed 1100+ commercial-off-the-shelf (COTS) and government off-the-shelf (GOTS) tools listed by name and vendor. Tool mappings were also made to the processes in two systems engineering standards—EIA-632, *Processes for Engineering a System*, and IEEE-1220, *Standard for the Application and Management of the Systems Engineering Process*—and the IMPIG WG Tool Taxonomy. A Requirements Management Survey and a Systems Engineering Tools Survey are available through the INCOSE Tools Database Working Group's website at http://66.34.135.97/tools/.

B. NATIONAL DEFENSE INDUSTRIAL ASSOCIATION

The National Defense Industrial Association (NDIA) has participation by the Aerospace Industries Association (AIA), the Institute of Electrical and Electronic Engineers (IEEE), INCOSE, the National Training Systems Association (NTSA), the American Institute of Aeronautics and Astronautics (AIAA), the Society of Logistics Engineers (SOLE), the Electronic Industries Alliance (EIA), the Society of Automotive Engineers (SAE) International, and the Government Electronics and Information Technology Association (GEIA). The NDIA has a Systems Engineering Division and a Naval Industry Advisory Council that are of interest here.

1. Systems Engineering Division

The NDIA has a Systems Engineering Division (SED) that was formed from its previous Systems Engineering Committee (SEC). The SEC was established in 1999 to "promote the widespread use of systems engineering in the DOD acquisition process." The Division consists of eight committees, including the Systems Engineering Disciplines Committee, which "attempts to identify those key critical skills and tools that are essential for implementation of a robust systems engineering process" and promotes best practices. The Training Committee "seeks to identify training methodologies for implementing and institutionalizing the necessary disciplines and skills of systems engineering" and works on establishing cross-training between industry and government." Other committees include Quality Assurance, Software, Modeling and Simulation, Life Cycle Support, Integrated Diagnostics, and Automatic Test.

Besides performing tasks for the Defense Science Board, SED is a co-sponsor of the Capabilities Maturity Model Integration (CMMI) project with the Office of the Secretary of Defense (OSD). The SED leads activities on enhancing best technical and business practices in COTS, open-systems architecture, the systems engineering discipline, supportability, training, diagnosis, affordability, and quality. For example, it

was engaged in a "summary review of OSD-level initiatives concerning the acquisition and sustainability of weapon systems," after which it made recommendations to OSD.

The SED holds annual conferences on Systems Engineering and Supportability and on Interoperability and Systems Integration.

2. Naval Industry Advisory Council

The Office of the Chief Engineer for Research, Development and Acquisition (RDA/CHENG) in the Navy has established the Naval Industry Advisory Council with the NDIA. The council consists of the Chairs of four NDIA major divisions or committees—Systems Engineering, Strike Land Attack and Air Defense, Expeditionary Warfare, and Undersea Warfare—plus the Chair of the Interoperability Sub-committee of the Systems Engineering Committee (now Division). The purpose of the advisory council is to "assist the Navy in engineering and implementing component systems to operate coherently with other systems as part of the larger military force." Systems engineering-related activities of the Council include reviewing and providing feedback to RDA-CHENG regarding potential systems engineering policies and the proposal of systems engineering issues and policies that need to be addressed from a Navy perspective.[83]

C. ELECTRONIC INDUSTRIES ALLIANCE

The Electronic Industries Alliance (EIA) represents the electronics industry through a federation of industry-related sectors and associations. The EIA fosters connections within the electronic industries; projects power and influence in terms of mapping the future of technology and public policy; provides industry and market research, data, analysis, and forecasts; and develops standards important to the electronic industries. [84]

EIA consists of six autonomous, yet united, associations relevant to the electronic industries. These associations are the Telecommunications Industry Association (TIA); the Consumer Electronics Association (CEA); the Electronic Components; Assemblies and Materials Association (ECA); the Government Electronics and Information Technology Association (GEIA); the JEDEC Solid State Technology Association; and the Electronic Industries Foundation (EIF). The Government Electronics and Information

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[83] http://www.ndia.org/committees/syseng/navalcouncil.cfm.

[84] "Benefits," EIA website, http://www.eia.org/members/benefits/index.cfm, 30 November 2000.

Technology Association (GEIA) Systems Engineering Committee, in particular, has been instrumental in developing many systems engineering standards.

The GEIA is the government market sector of the EIA, composed of electronics and information technology industries that conduct business with the government. The G-47 committee, *Systems Engineering*, is part of GEIA's Systems, Standards and Technology Council. The G-47 committee develops systems engineering management concepts, taking into account the entire product life cycle, its processes, and its elements. It also "deals with the integration and coordination of the various specialty efforts into the overall systems engineering process." Currently, G-47 is monitoring feedback on the EIA systems engineering standards: ANSI/EIA-632, *Processes for Engineering a System*, and EIA-731, *Systems Engineering Capability Model (SECM).* (See Sections V.A.2 and V.B.1 for more on these standards.) Recently, the committee voted to convert the interim standard, EIA/IS-731, to a full standard. EIA/IS-731 was a source model for the CMMI project, so as EIA-731, *SECM*, is promoted to a full standard, the G-47 is also developing a sunset plan to allow users time to transition to the CMMI-SE/SW model.

In September 2003, the GEIA G–47 Systems Engineering Panel published *The Next Generation of Systems Engineering* based upon a previous panel workshop with representatives presenting their relevant initiatives and technologies covering processes; methods, techniques, and standards; engineering environments and tools; and modeling and simulation. "The purpose of this panel was to present a set of visions about *how Systems Engineering will transform the engineering of systems in the next decade* through development and application of concepts under current Research and Development (R&D)."[85] In the end the panel made the following two recommendations: [86]

- Conduct a workshop that assembles both tool vendors and engineering environment builders
- Establish a new Working Group within the GEIA G–47 Systems Engineering Committee "to define and document a Vision of the next generation of [systems engineering] capabilities"

Other GEIA committees of relevant interest are G-34, *the Software Sub-Committee*, and G-33, *Configuration and Data Management*.

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[85] Government Electronics and Information Technology Association "The Next Generation of Systems Engineering: A Report by the GEIA G–47 Systems Engineering Panel, GEIA Engineering Bulletin, GEIA-SE-0001, September 2003, p. i.

[86] Ibid, p. iii.

D. AEROSPACE INDUSTRIES ASSOCIATION

The Aerospace Industries Association (AIA) represents the nation's major manufacturers of commercial, military, and business aircraft; helicopters; aircraft engines; missiles; spacecraft; and related components and equipment in the U.S.[87] The Technical Operations Department develops and integrates standards, requirements, and policy relating to aerospace issues. Within the Technical Operations Department are the following committees relevant to systems engineering:

- Engineering Management
- Manufacturing and Materiel Management
- Product Support
- Quality Assurance
- National Aerospace Standards

In 2001 the AIA relayed issues to the Commission on the Future of the United States Aerospace Industry. In conjunction with that commission, the AIA published a white paper titled "Education Infrastructure and National Education Programs are Not Being Adequately Utilized."

E. INSTITUTE OF ELECTRONIC AND ELECTRICAL ENGINEERS

The IEEE is an international professional association. The Systems, Man, and Cybernetics (SMC) Society within the IEEE publishes the *IEEE Transactions on Systems, Man, and Cybernetics*. Part A of this publication is devoted to the fields of systems engineering and human machine systems. Part C, *Applications and Reviews*, also includes systems engineering articles.

The Software Engineering Standards Committee (SESC), part of the IEEE Computer Society, published IEEE-1220, *Standard for Application and Management of the Systems Engineering Process*. (See Section V.A.3 for more on IEEE-1220.) The SESC has an active IEEE-1220 Working Group that is conducting a revision project for IEEE-1220 currently underway that includes coordination with ISO/IEC 15288, ISO/IEC 12207, ANSI/EIA-632, and INCOSE. The goal of the revision is to harmonize with ISO/IEC 15288, the CMMI-SE/SW, and the Software Engineering Body of Knowledge (SWEBoK).

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87 http://www.aia-aerospace.org/about/about.cfm.

F. AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS

The American Institute of Aeronautics and Astronautics (AIAA) is a nonprofit, global, professional association whose primary purpose is "to advance the arts, sciences, and technology of aeronautics and astronautics and to foster and promote the professionalism of those engaged in these pursuits."[88] The AIAA chartered a Systems Engineering Technical Committee (SETC) in 1993 as a Technical Committee under the Engineering and Technology Management Group. The purpose of the SETC is "to foster the definition, dissemination, development, understanding, and application of systems engineering processes, methodologies, and tools to aeronautics, space, computer and ground stations." The SETC accomplishes these objectives through the following activities:

- Disseminating information about professional development opportunities
- Developing systems engineering chapters in AIAA handbooks
- Participating in the development of emerging national and international standards and guidelines
- Developing systems engineering application training courses for AIAA systems engineers
- Running the systems engineering track in the Digital Avionics Systems Conference

Some of the systems engineering professional development courses offered by the AIAA include a fast-track tutorial and short courses on risk management, spacecraft thermal control, effective risk management, resolving requirements conflicts, and spacecraft systems design and engineering. Online tutorials include "A System Engineer's View of Spacecraft Avionics" by Robert Moore at the Johns Hopkins University Applied Physics Lab.[89]

The SETC also undertakes joint projects with NDIA and INCOSE.

G. ISO/IEC SUBCOMMITTEE 7, SOFTWARE AND SYSTEMS ENGINEERING

The International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC) have a Joint Technical Committee for *Information Technology*, JTC1. JTC1 is divided into 17 subcommittees (SCs) according to the

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88 *About AIAA: Mission Statement*, website, http://www.aiaa.org/about/index.hfm.

89 AIAA Professional Development website, List of Courses and Online Tutorials, http://www.aiaa.org/professional/index.hfm.

specific use and application of information technology within different sectors. SC7 is *Software and System Engineering*, which consists of 28 participating countries and 18 observer countries.[90] SC7 is divided into 11 working groups (WGs). Those most pertinent to systems engineering are WG7, *Life Cycle Management*, and WG10, *Process Assessment*.

The Institute of Electrical and Electronic Engineers is the U.S. member organization to JTC1 SC7. It runs the U.S. Technical Advisory Group (TAG). Operationally, the day-to-day work on behalf of the United States is performed by the U.S. TAG, consisting of task groups (TGs) that correspond to each of JTC1 SC7's WGs. DoD and IDA participate in the U. S. TAG to SC7, *Software and System Engineering*. The work on life cycle process standards and assessments occurs in TG7, *Life Cycle Management*, and TG10, *Process Assessment*.

H. ISO TECHNICAL COMMITTEE 184, *INDUSTRIAL AUTOMATION SYSTEMS AND INTEGRATION*, SUBCOMMITTEE 4, *INDUSTRIAL DATA STANDARDS*

ISO Technical Committee (TC) 184, *Industrial Automation Systems and Integration*, Subcommittee (SC) 4, *Industrial Data Standards*, is the TC that develops the STandard for the Exchange of Product model data (STEP). (See Section V.V.1 for more on STEP.)

I. PDES, INC. AND US PRO

PDES, Inc. is a consortium of industry and government members in the United States and the United Kingdom to accelerate the development and implementation of product data exchange using STEP. The U.S. Product Data Association (US PRO) is the organization responsible for U.S. participation in information standards development and education. The Advanced Technology Institute (ATI) in North Charleston, South Carolina, is the leader for these two organizations. [91]

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[90] "JTC1 SC7—Software and System Engineering," ISO website, http://www.iso.ch/en/std…lPage.TechnicalCommitteeDetail?COMMID=40.html, 26 November 2001.

[91] See Section VII.D. for more information on ATI.

J. SYSTEMS ENGINEERING DOMAINS SPECIAL INTEREST GROUP

The Systems Engineering Domains Special Interest Group (SEDSIG) was formed through a liaison of INCOSE and the Object Management Group (OMG) to pursue the Unified Modeling Language (UML) for systems engineering.

V. STANDARDS AND MODELS

Standards and models play an important part in defining a disciplined, effective systems engineering process. This chapter discusses three systems engineering process standards and two process models and concludes with some information on data modeling standards. The process standards include—

- ISO/IEC 15288, *Systems Engineering—System Life Cycle Processes*
- ANSI/EIA-632, *Processes for Engineering a System*
- IEEE-1220, *Standard for the Application and Management of the Systems Engineering Process*

The process models include—

- EIA-731, *Systems Engineering Capability Model*
- *Capability Maturity Model-Integration for Systems Engineering, Software Engineering and Integrated Product and Process Development and Supplier Sourcing (CMMI-SE/SW/IPPD/SS)*

A. PROCESS STANDARDS

1. ISO/IEC 15288, *Systems Engineering—System Life Cycle Processes*

Developed and published by the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC), ISO/IEC 15288, *Systems Engineering—System Life Cycle Processes*, covers the life cycle of a manmade system from concept through retirement. "It provides the processes for acquiring and supplying system products and services that are configured from one or more of the following types of system components: hardware, software, and humans. In addition, the framework provides for the assessment and improvement of the life cycle." This standard is designed for use by an organization, a project within an organization, or an acquirer and a supplier via an agreement.

The processes in ISO/IEC15288 are grouped into four categories: Agreement, Enterprise, Project, and Technical. Each process within the standard consists of a process purpose, outcomes, and activities, but it is the accomplishment of the outcomes that gives evidence that the requirements of an organization's declared set of processes (those that apply to its business objectives) are being met.

Underway since 1995, ISO/IEC 15288 and its Guide have recently been published. With ISO/IEC 15288 now officially available, two related yet separate efforts are underway to harmonize systems engineering-related standards. The first effort involves the harmonization of ISO/IEC 15288; ISO/IEC 12207, *Software Life Cycle Processes*; ISO/IEC 15504, *Process Assessment*; and ISO 9000-3, *Application of ISO 9001:2000 to Software*. The second harmonization effort, with the IEEE Computer Society's Software Engineering Standards Committee, encompasses ISO/IEC 15288 and IEEE-1220, *Standard for the Application and Management of the Systems Engineering Process*.

2. EIA-632, *Processes for Engineering a System*

During the summer of 1994, the EIA established an EIA Working Group, which worked toward the development of EIA Interim Standard (IS) 632:1994, *Processes for Engineering a System*. This standard was the commercial equivalent to MIL-STD-499B, *Systems Engineering*, which was never published due to DoD's move toward the use of commercial standards. The EIA was joined in this effort by the Aircraft Industry Association (AIA), DoD, the National Security Industries Association (NSIA), the Institute of Electrical and Electronic Engineers (IEEE), and the International Council on Systems Engineering (INCOSE). In 1998, EIA-632, P*rocesses for Engineering a System*, became a full standard. In addition to 632, the EIA has developed other standards such as interim standard EIA/IS-731, *Systems Engineering Capability Model (SECM) and Appraisal Method*. The EIA also coordinated with the IEEE on IEEE/EIA 12207:1996: *Standard for Information Technology—Software life cycle processes*.

The purpose and scope of EIA-632 is to "provide an integrated set of fundamental processes to aid a developer in the engineering and reengineering of a system." The processes presented in this standard are divided into five categories: Acquisition and Supply, Technical Management, System Design, Product Realization, and Technical Evaluation. The processes in ANSI/EIA-632 describe "what to do" with respect to the processes for engineering a system, which is the next level down from the ISO/IEC 15288 level of system life cycle processes. Each of these processes is described in terms of requirements.

At the moment, ANSI/EIA-632 remains removed from any ongoing efforts to harmonize systems engineering-related standards (e.g., ISO/IEC 15288 and IEEE-1220).

3. IEEE-1220, *Application and Management of the Systems Engineering Process*

The IEEE originally released in 1995 a "Trial-Use" standard which was later published in 1998 as the full, authorized standard, IEEE-1220, *Application and Management of the Systems Engineering Process*. The purpose and scope of IEEE-1220 is to "provide a standard for managing a system from initial concept through development, and define life cycle disposal."

The processes in IEEE-1220 are divided into those for the life cycle, i.e., development, manufacturing, test distribution, operation, support, training, and disposal and those for the Systems Engineering Process (SEP), i.e., requirements analysis, requirements validation, functional analysis, functional verification, synthesis, design verification, systems analysis, and control. The process descriptions provide "interdisciplinary tasks that are required throughout a system's life cycle to transform customer needs, requirements, and constraints into a system solution." The processes contained in IEEE-1220 give the next level of detail below the process requirements described in EIA-632 and are more at the task or application level.

SC7 of the JTC 1 of ISO/IEC created an Ad Hoc System Engineering Study Group that surveyed the utility of the systems engineering standards for an organization implementing a systems engineering approach. The Study Group determined that an organization would need ISO/IEC 15288, EIA-632, and IEEE-1220. ISO/IEC 15288 defines the processes needed during a system's life cycle, EIA-632 defines the set of requirements for engineering a system, and IEEE-1220 defines the systems engineering process itself. An approach has been proposed for harmonizing these three documents and making them consistent with each other. An effort is underway to bring about the harmonization of IEEE-1220 and ISO/IEC 15288.

B. CAPABILITY AND MATURITY MODELS

1. EIA-731, Systems Engineering Capability Model

In 1966, the EIA G-47 Systems Engineering Committee chartered a project to combine two existing systems engineering models: the Enterprise Process Improvement Collaboration (EPIC) project's Systems Engineering Capability Maturity Model (Systems Engineering-CMM) and INCOSE's Systems Engineering Capability Assessment Model (SECAM). The result of the project was that EIA published the EIA Interim Standard (EIA/IS)-731-1, *Systems Engineering Capability Model (SECM)*, and EIA/IS-731-2, *Systems Engineering Capability Model (SECM) Appraisal Method*. Thus, Volume 1

contains the model and Volume 2 is the appraisal method. The model contains Generic Practices and Generic Attributes that are grouped into the four levels of capability above level 1, which contains none.[92] The capability levels of the model are as follows:

1. Performed
2. Managed, where activities are planned and tracked
3. Defined, where activities are performed according to a well-defined process using approved versions of standard and documented processes (may be tailored)
4. Measured, where measurement is applied to the processes
5. Optimizing, where quantitative performance goals for process effectiveness and efficiency based on business goals are established

The SECM was originally published as an interim standard by the EIA because it was to be used as a source model for the Capability Maturity Model Integration (CMMI) and would be canceled once the CMMI was published. Changes in the rules and regulations governing EIA standards has eliminated the "Interim Standard" designation, so it has been published as a full standard.

2. Capability Maturity Model Integration

The CMMI model integrates EIA-731, *Systems Engineering Capability Model (SECM)*, the *Software CMM*, and the *Integrated Product Development (IPD) CMM* to provide a model for process integration and improvement across an organization. The CMMI is actually a framework that can be used to produce various combinations of models based on the disciplines for which models exist. Currently, CMMI models exist for systems engineering, software engineering (SW), integrated product and process development (IPPD), and supplier sourcing (SS). The CMMI will be used by both government and industry for self-assessments to increase their process capability and organizational maturity. The DoD's goal is to select mature contractors with capable processes.

Whereas the Software CMM uses a staged representation, EIA-731 uses a continuous representation. In a staged representation, specific process areas are required for each maturity level, and an organization gets rated on its maturity. In a continuous representation, the organization chooses the set of process areas that applies to its

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[92] EIA/IS 731.1, *Systems Engineering Capability Model (SECM)*.

business objectives and then each process area gets individually assessed to a capability level. The CMMI has both a staged representation and a continuous representation. An Equivalent Staging Diagram published in the CMMI models shows an equivalence between the two representations. To be equivalent to a Maturity Level 3 rating for an organization, it would have to be capability level 3 in all of the process areas listed in the equivalency diagram.

The maturity levels within the CMMI framework are as follows: 1) Initial, 2) Managed, 3) Defined, 4) Quantitatively Managed, and 5) Optimizing. The capability levels are the same except that a process can be at capability level 0, Incomplete, as well. A maturity level for an organization of "incomplete" does not make sense in the context of the CMMI.

While the CMMI-Systems Engineering/Software/IPPD model was being developed, a need was perceived for a model version with the "acquisition" discipline added, and an attempt was made to incorporate the Software Acquisition CMM. This effort evolved into a more succinct addition of a supplier sourcing (SS) discipline, to create a CMMI-Systems Engineering/SW/IPPD/SS model. In 2004 additional work was done to develop an acquisition module, CMMI—A.

The CMMI is a collection of best practices, grouped into categories called "Process Areas," but these are not really processes nor is the CMMI a process model, so it is in a slightly different category than the standards.

C. DATA INTERCHANGE AND MODELING

1. STEP

The STandard for the Exchange of Product (STEP) model data is published by ISO. It has become the internationally recognized standard for product data exchange by virtue of its neutral universal file format that helps alleviate problems caused by different proprietary methods used by software vendors in product development and manufacturing. Application protocols within STEP are being developed to enable real-time, consistent, and accurate data exchange between different hardware and software. STEP will enable small suppliers to work with many companies without having to have specific hardware and software for each customer. "Product development strategies, such

as concurrent engineering, enterprise integration, electronic commerce, and quality function deployment, will significantly benefit from the use of STEP."[93]

The standard is issued as ISO 10303. This standard is being developed by the ISO Technical Committee (TC) 184, Industrial Automation Systems and Integration, Subcommittee (SC) 4, *Industrial Data Standards*. STEP uses the EXPRESS data modeling language described in STEP Part 11, EXPRESS Language Reference Manual. Thus, STEP is computer sensible, unlike other data transfer standards. The architecture of STEP consists of five main groupings:

- Description methods
- Implementation methods
- Conformance methodology
- Integrated-information resources
- Application protocols (APs)

The APs are the most complex data models used to describe specific product data applications in specific domains.[94] There are currently 39 application protocols identified in the STEP suite, 3 of which have been completed and published as international standards. One of the most common APs for CAD and CAE systems is AP 203, *Configuration Controlled Design*. AP 233, *Systems Engineering Data Representation*, "provides a neutral format for exchange of systems engineering data between tools."[95] In total, STEP will provide a "description of the physical and functional characteristics of a product throughout its life cycle."[96]

2. AP-233, *Systems Engineering*

SEDRES is the Systems Engineering Data Representation and Exchange Standardisation project producing the STEP-based application protocol (AP) 233, *Systems Engineering*. It was published in 2001 and designed to enable a standardized data exchange capability for the different tools used in systems engineering. "A significant issue arising from the Project is the usability of such a data transfer capability

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93 "The Importance of STEP," http://pdesinc.aticorp.org/whystep.html, date unknown.

94 "STEP on a Page," http://pdesinc.aticorp.org/whystep.html, date unknown.

95 Sanford Friedenthal, *AP-233 Overview*, 13 September 2001.

96 "PDES, Inc.," http://pdesinc.aticorp.org/whatsnew/pdesflyer_99.html, date unknown.

and its effectiveness in the systems engineering process, especially in its application in the support of integrated product teams (IPTs)."[97]

3. UML for Systems Engineering

A joint INCOSE and Object Management Group (OMG) initiative exists to extend the Unified Modeling Language (UML) to systems engineering.

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[97] David Harris and Linda Candy, "Evaluation in the SEDRES Project: Measuring the Effectiveness of Model Data Exchange between System Engineering Tools," Ninth Annual International Symposium of the International Council on Systems Engineering (INCOSE), 6–10 June 1999. Other SEDRES articles have been covered in prior years of the symposium as well.

VI. ACADEMIC OPPORTUNITIES

This chapter will demonstrate the wide range of academic programs that describe themselves as being "systems engineering." A definition of just what constitutes systems engineering education is one problem that INCOSE is already addressing. There is no professional, academic standard for what constitutes a curriculum or degree in systems engineering. Two students—each with a degree in systems engineering, but from two different programs—can have very different backgrounds, coursework, and education behind their degrees. Also, since it is not defined in the same way as, say, mechanical engineering or electrical engineering, neither the National Science Foundation nor the American Society of Engineering Education (ASEE) collects statistics on systems engineering students, courses, programs, and degrees. Professionally, not having the discipline of systems engineering academically defined means that it often lags behind in status compared with the more prominent engineering disciplines.

In addition to undergraduate and graduate systems engineering programs, this paper also covers certificate programs, which generally arise in conjunction with graduate programs to fulfill a more specific industry or defense need. Certificate programs tend to include some amount of work experience.

First, we begin with a discussion of accreditation for the academic programs.

A. ABET ACCREDITATION

The Accreditation Board for Engineering and Technology (ABET) is a federation of 31 engineering and technical professional societies. Formed in 1932, it is the quality assurance organization for engineering and technology education through its issuance of accreditations. ABET accreditation of engineering, technology, and applied science programs is recognized by the Council on Higher Education.

ABET accredits programs through an evaluation of eight criteria. These criteria are:

1. Students
2. Program Educational Objectives
3. Program Outcomes and Assessment
4. Professional Component

5. Faculty
6. Facilities
7. Institutional Support and Financial Resources
8. Program Criteria

The eighth criterion is the specific program criteria (curricula topics and faculty qualifications) for a given discipline, if they exist. To date, no program criteria exist for the systems engineering discipline. Thus, systems engineering programs can be ABET accredited without satisfying any program criteria. Programs with names such as "Industrial and Systems Engineering" would have to satisfy the Industrial Engineering criteria, which do exist, but the systems engineering component remains undefined. Software Engineering, on the other hand, does have specified program criteria.

B. ACADEMIC INSTITUTIONS OFFERING SYSTEMS ENGINEERING

Appendixes A, B, and C contain detailed information on the U.S. academic programs that offer undergraduate degrees, graduate degrees, and certifications in systems engineering, respectively. The degree programs are separated into two categories as defined by Dr. Wolter Fabrycky: discipline-centric systems engineering programs and domain-centric programs that include systems in the major. This distinction helps separate those programs focused on "pure" systems engineering, as, say, defined by INCOSE, and those that overlap with other disciplines. This distinction is subjective due to the disagreement and lack of consensus among the community about what constitutes systems engineering. We found the distinction to be helpful, however, and have chosen to adopt it here.

There are also disagreements among the academic community members about whether systems engineering can be taught at the undergraduate level. All of the military schools now offer an undergraduate systems engineering degree, but in general, the feeling is that a good systems engineer only develops with a lot of experience, which only occurs with graduate programs or certificate programs.

Certificate programs often arise from a specific industry need. The following section describes some of the special arrangements that some defense companies are pursuing.

C. INDUSTRY RELATIONSHIPS WITH ACADEMIC INSTITUTIONS

Many companies have developed their own education and training programs in cooperation with local universities. Some of them are included below.

1. Lockheed Martin

Some of the courses for the graduate degree in systems engineering from the University of Pennsylvania are taught at Lockheed-Martin Valley Forge.

Based on money received from the Department of Trade and Economic Development, the University of Minnesota (UMN) developed a 3-year certificate program in systems engineering through the College of Continuing Education (CCE) aimed at Lockheed-Martin employees. According to UMN's *Brief* it will "provide 160 Lockheed Martin engineers with skills enhancement education and opportunity to pursue a credit certificate in systems engineering."[98]

2. Boeing

Boeing has a relationship with the University of Southern California offering both a master of science in systems architecture and engineering (MS SAE) and a graduate certificate. One unique aspect of the MS SAE or graduate certificate is that all of the required courses are offered through the Distance Education Network (DEN). The courses are delivered via Internet or satellite feed (where available). Satellite (one-way video, two-way audio) was originally set up in special classrooms at affiliated corporations in the local USC area, but now by using the Internet, students are able to access courses anytime and anywhere, which is ideal for those working students who travel extensively. Dr. Elliot Axelband is the Director of the SAE program and there is a joint collaboration with the University of Missouri at Rolla.

3. Raytheon

Raytheon has a co-op/intern program; however, out of about 16 locations nationwide, systems engineering majors can only participate through the St. Petersburg, Florida, location.

The Integrated Product and Process Design (IPPD) program is a new educational initiative in the College of Engineering, University of Florida. Students work in small multidisciplinary teams under the guidance of faculty coaches and industrial liaison engineers to design and build authentic industrial products for sponsoring companies.

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[98] "Brief," University of Minnesota, vol. XXXII, no. 12, 3 April 2002, http://www1.umn.edu/urelate/brief/2002-040-3.html.

Through an initiative sponsored by the NDIA, Raytheon has recently opened its corporate training classes to government personnel, similar to the way that industry personnel can take the Program Management course at DAU.

4. Northrop Grumman

Northrop Grumman has a relationship with Old Dominion University for systems engineering training and education.

The Electronics Systems Division has an internship program suitable for engineering majors and a New Graduate Professional Development Program. This is an "intensive, rotational program for entry-level engineers, technical staff specialists, and administrative staff personnel."[99] There are four 2- to 4-month program assignments, mostly based in Baltimore. Participants in this program are full-time employees with a full salary and benefits package.

[99] "New Graduate Professional Development Program," website, http://www.es.northropgrumman.com/es/jobs/pdp.htm.

VII. ACADEMIES AND CENTERS

This chapter focuses on some other institutions that provide a forum for systems engineering.

A. NATIONAL ACADEMY OF ENIGNEERING

The National Academy of Engineering (NAE) located in Washington, DC, is a private, independent, nonprofit institution that conducts its own research, advises the federal government on engineering and technology issues, and reports to Congress. It has conducted two projects in systems engineering. The first one is a NAE and Air Force Science and Technology Board project entitled "The Future of the US Aerospace Infrastructure and Aerospace Engineering Disciplines to Meet the Needs of the Armed Forces and the Department of Defense." It has been completed, with a report published in 2001. The second is a Program on Earth Systems Engineering, designed "to predict and to monitor the ecological impact of engineered systems, and to devise engineered systems for the mutual benefit of nature and human-made systems." A report, *Engineering and Environmental Challenges: Technical Symposium on Earth Systems Engineering*, was published in October 2002. [100]

B. FEDERALLY FUNDED RESEARCH AND DEVELOPMENT CENTERS

1. Institute for Defense Analyses (IDA)

The Institute for Defense Analyses (IDA) in Alexandria, Virginia, is a research and analysis federally funded research and development center (FFRDC) that has been working policy issues on systems engineering for the Office of the Secretary of Defense since the office was formed in 1994 by then Principal Deputy of Acquisition and Technology, Noel Longuemare. IDA also has supported the Systems Engineering Office in the specialty areas of reliability and maintainability, quality, and risk management.

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[100] "Frequently Asked Questions," http://www.nae.edu/nae/naehome.nsf/weblinks/NAEW-4NHME3?OpenDocument.

2. Software Engineering Institute

The Software Engineering Institute (SEI) was established by DoD as an FFRDC because of the importance of quality software, delivered on time and within budget, to the development and procurement of defense systems.[101] In order to facilitate this relationship between defense systems and software, SEI's mission is to "provide leadership in advancing the state of the practice of software engineering to improve the quality of systems that depend on software."[102] SEI is chartered to: [103]

- Bring the ablest professional minds and the most effective technology to bear on the rapid improvement of the quality of operational software in systems that depend on software
- Accelerate the reduction to practice of modern software engineering techniques and methods
- Promulgate the use of modern techniques and methods throughout the defense community

During the early 1990s the SEI produced various versions of the Capability Maturity Model for Software (the "CMM"), based on "the" vision of Watts Humphrey, the first director of the SEI's Software Process Program. An assessment method was also developed for the CMM. In part due to the success of this model, the SEI provided project management and administrative support to EPIC to produce the *Systems Engineering–Capability Maturity Model (SE–CMM)* and the *SE–CMM Appraisal Method (SAM)*, which were released as SEI documents. The SEI produced other capability maturity models (CMMs) and assessment methods, such as the Integrated Product Development (IPD) CMM and the People CMM. The SEI, with government and industry sponsorship, ultimately developed the Capability Maturity Model Integration (CMMI) and its appraisal method.

3. MITRE

MITRE was founded in 1958 as "a private, not-for-profit corporation to provide engineering and technical services to the federal government."[104] MITRE's original work focused solely on the Department of Defense (DoD). Today, MITRE manages three

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101 The specific contract for the SEI FFRDC is held by Carnegie Mellon University.

102 "About the SEI— Welcome," SEI/Carnegie Mellon website, http://www.sei.cmu.edu/about/about.html, 27 November 2001.

103 "The SEI Charter," SEI/Carnegie Mellon website, http://www.sei.cmu.edu/about/overview/sei/charter.html, 27 November 2001.

104 "MITRE History," MITRE website, http://www.mitre.org/about/history.html, 11 February 2004.

FFRDCs—the DoD Command, Control and Communications and Intelligence FFRDC; the Center for Advanced Aviation Systems Development FFRDC for the Federal Aviation Administration; and the Center for Enterprise Modernization FFRDC for the Internal Revenue Service.[105] In addition to this, however, MITRE is often associated with being a systems engineering FFRDC. Indeed, throughout its history, MITRE has "provided successful systems engineering expertise on a range of vital projects from the SAGE intercontinental defense system in the 1950s and the SATIN prototype air traffic control system in the 1950s and 1960s to [its] current work developing enterprise architectures for the Internal Revenue Service, the Federal Aviation Administration, and the Department of Defense."[106] MITRE's systems engineering-related skills include architectures, strategic planning, systems integration, and risk analysis.

4. Aerospace Corp.

The Aerospace Corporation, another systems engineering FFRDC, is an FFRDC for the Air Force Space Command, Air Force Space and Missile Systems Center, the National Reconnaissance Office, and other government agencies. Its activities center on "hands-on engineering associated with the design, test, evaluation, and initial operation of space systems."[107] The FFRDC also provides technical advice on systems development, acquisition, system-of-systems engineering, process implementation, launch certification, and technological application. It has employed systems engineering in several programs, such as the Mercury/Atlas project and GPS/inertial navigation for precise weapon delivery. Also, the Systems Architecture and Engineering program works on, *inter alia*, systems and operations safety. Finally, the Engineering and Technology Development program "provide[s] broad systems engineering support for tracking and communications with pico [satellites] from the large 50-meter dish operated by SRI International in Palo Alto, California."[108]

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105 "Corporate Profile," MITRE website, http://www.mitre.org/about/index.html, 7 January 2003.

106 "Systems Engineering," MITRE website, http://www.mitre.org/work/systems_engineering.html, 10 September 2004.

107 "Corporate Overview—An Introduction," The Aerospace Corporation website, http://www.aero.org/overview/introduction.html, 20 May 2003.

108 "Engineering and Technology Development," The Aerospace Corporation website, http://www.aero.org/technology/etd.html, 14 June 2000.

C. SOUTHWEST RESEARCH INSTITUTE

The Southwest Research Institute (SWRI), headquartered in San Antonio, Texas, is an "independent, nonprofit applied research and development organization."[109] It provides advanced systems engineering, software development, and systems integration and design for government, commercial, and foreign clients.

D. ADVANCED TECHNOLOGY INSTITUTE

The Advanced Technology Institute (ATI) in North Charleston, South Carolina, engages in consortia leadership and research and development. Its Product Development Technology business unit is involved in the areas of modeling and simulation and systems engineering.[110] In addition, ATI's Infrastructure Protection Technology unit provides technical assistance in the design and implementation of secure systems.

E. INFORMATION ANALYSIS CENTERS

Information Analysis Centers (IACs) are formal organizations chartered by the Department of Defense to assist in locating, analyzing, and using scientific and technical information. An IAC's primary mission is "to improve the productivity of researchers, engineers, and program managers in the Defense research, development, and acquisition communities by collecting, analyzing, synthesizing, and disseminating worldwide scientific and technical information in clearly defined, specialized fields or subject areas."[111] Secondarily, an IAC promotes standardization within its field of concern. An IAC has the following four strategic goals: 1) providing excellent customer service, 2) making access to information easy, 3) promoting the use of information to enhance decision-making and leverage of the technology base; and 4) promoting excellence in its Human Resources.[112] The Office of the Secretary of Defense, Director of Defense Research and Engineering, provides the policy oversight for the IACs. The Defense Technical Information Center (DTIC), through the Defense Information Systems Agency (DISA), provides administrative and operational management, while an appointed Contracting Officer's Technical Representative (COTR) provides technical management.

The IACS provide expertise and training on a fee-for-service basis.

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109 About SwRI, http://www.swri.edu/swri.htm.

110 ATI Product Development Technology, http://www.aticorp.org/pdt.htm.

111 "About—IAC Mission," Department of Defense Information Analysis Centers, http://cseriac.flight.wpafb.af.mil/1_about/about_mission.htm.

112 Ibid.

1. Reliability Analysis Center

The Reliability Analysis Center (RAC) is an IAC with the mission to "provide technical expertise and information in the engineering disciplines of reliability, maintainability, supportability, and quality and to facilitate their cost-effective implementation throughout all phases of the product or system life cycle."[113] With a technical scope that includes both military and commercial systems and products, the RAC provides data/information and the technical staff to address virtually any issue related to reliability, maintainability, quality, and supportability. Specific areas of expertise include reliability program management; reliability data collection and analysis; reliability modeling and prediction; parts control programs and part qualification; failure reporting and corrective action system (FRACAS); systems/equipment lifetime extension analysis; failure mode, effects & criticality analysis (FMECA); fault tree analysis (FTA); worst case circuit analysis (WCCA); testability and maintainability analysis; reliability-centered maintenance (RCM); electrostatic discharge (ESD) susceptibility analysis; reliability/maintainability test planning and control; environmental stress screening (ESS) planning; mechanical reliability and maintainability; finite element analysis (FEA); quantitative services; total quality management; environmental characterization; component obsolescence; system supportability; and supply chain management. The RAC's management and technical sponsors are DTIC and the Systems Engineering Office under the Office of the Under Secretary of Defense (Acquisitions, Technology and Logistics), respectively. The RAC is located in Rome, New York, and is operated by the IIT Research Institute (IITRI).

2. Advanced Materials and Processes Technology Information Analysis Center

The Advanced Materials and Processes Technology Information Analysis Center (AMPTIAC) is an IAC "charted by the Department of Defense to serve as a government and industry focal point of data and information relating to advanced materials and processes."[114] Sponsored by DTIC, IIT Research Institute holds the contract for the AMPTIAC, which consolidated the work of 13 other material IACs, including the Ceramic Information Analysis Center (CIAC), High-Temperature Materials Information Analysis Center (HTMIAC), Metals Information Analysis Center (MIAC), Metal Matrix

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[113] "Reliability Analysis Center (RAC) Mission Statement," Reliability and Maintainability Center website, http://rac.iitri.org/About/Rac_Mission.html, 14 August 2001.

[114] "AMPTIAC's Mission," Advanced Materials and Processes Technology IAC website, http://amptiac.iitri.org/About/about_mission.html.

Composites Information Analysis Center (MMCIAC), and Plastics Information Analysis Center (PLASTEC). Since its opening in Rome, New York, in 1996, AMPTIAC's scope has expanded beyond that of these previous materials-related IACs to include metals, alloys, and metal matrix composites; organic structural materials and organic matrix composites; ceramics and ceramic matrix composites; electronic, optical, and photonic materials; and environmental protection and special functions.

3. Human Systems Information Analysis Center

The Human Systems Information Analysis Center (HSIAC) serves as "the gateway to worldwide information on human systems integration in sea, land, air, and space environments," through providing "a variety of scientific and technical information products and services to government, industry, and academia dealing with the component of a system."[115] The HSIAC's domains of knowledge are: human systems; habitability; human factors; health hazards; medical factors; personnel survivability; safety; and manpower, personnel and training (MPT).[116] DTIC and the Air Force Research Lab's Human Effectiveness Directorate, respectively, sponsor and technically manage the HSIAC. HSIAC is operated by Booz-Allen & Hamilton, Inc.

4. Modeling and Simulation Information Analysis Center

The Modeling and Simulation Information Analysis Center (MSIAC) is an IAC that "assist[s] Department of Defense activities in meeting their [Modeling & Simulation] M&S needs by providing scientific, technical, and operational support information and services."[117] The MSIAC's mission is "to access, acquire, collect, analyze, synthesize, generate, and disseminate scientific, technical, and operational support information in the area of modeling and simulation …"[118] This is accomplished by supporting DoD modeling and simulation activities, assisting "DoD components/offices, other Government agencies, academia, Government contractors, and U.S. industry as authorized, in the analysis and dissemination of information within the DoD modeling

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115 "Our Mission," Human Systems Information Analysis Center website, http://iac.dtic.mil/hsiac/mission.html, 21 June 2002.

116 "Domains," Human Systems Information Analysis Center website, http://iac.dtic.mil/hsiac/Domains.htm.

117 Modeling and Simulation Information Analysis Center website, http://www.msiac.dmso.mil/home_msiac.htm.

118 "About MSIAC," Modeling and Simulation Information Analysis Center website, http://www.msiac.dmso.mil/msosa-net/about asp.

and simulation areas,"[119] and promoting the exchange of MSIAC-related technical information throughout DoD's research, development, and acquisition communities. MSIAC's core competencies include weapons technology including WMD; information management; modeling and simulation; operations analysis; chemical and explosive sciences; material sciences; reliability, availability, and maintainability; spectrum engineering; wireless communication; life sciences; medical informatics and telemedicine; and transportation systems. MSIAC is located in Alexandria, Virginia, and is sponsored by DTIC and the Defense Modeling and Simulation Office (DMSO).

5. Manufacturing Technology Information Analysis Center

The Manufacturing Technology Information Analysis Center (MTIAC) "promotes the exchange of manufacturing technology information and supports the DoD Manufacturing Technology (ManTech) program objectives."[120] The MTIAC's technical scope includes the following: business or industry sector analysis; manufacturing technology; specialized manufacturing applications; low-risk production capabilities; process capabilities; factory operations; maintenance/repair processes; and low-cost spares acquisition. MTIAC is sponsored by DTIC and operated by IIT Research Institute in Chicago, Illinois.

6. Nondestructive Testing Information Analysis Center

By collecting, analyzing, and disseminating information related to nondestructive testing (NDT), the Nondestructive Testing Information Analysis Center (NTIAC) serves as the DoD center of expertise for nondestructive testing (NDT) technology. The NTIAC works for government agencies to conduct research through Technical Area Tasks (TATs) related to nondestructive testing. Some examples of TATs and other research include detection of corrosion under paint (CUP); NDE of aluminum gas cylinders; NDE for process control of single-crystal tungsten rods; probability of detection (POD) program plan development; NDE for submarine towed array systems; and post-sea trial nondestructive and destructive testing of Navy submarine composite transducer brackets.[121] NTIAC is sponsored by DTIC and operated by the Texas Research Institute Austin, Inc.

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119 Ibid.

120 Manufacturing Technology Information Analysis Center website, http://iac.dtic.mil/mtiac.

121 Nondestructive Testing Information Analysis Center website, http://iac.dtic.mil/ntiac/ntiactat.html.

7. Survivability/Vulnerability Information Analysis Center

The Survivability/Vulnerability Information Analysis Center (SURVIAC) serves as "the DoD focal point for non-nuclear survivability/vulnerability data, information, methodologies, models and analysis relating to U.S. and foreign aeronautical and surface systems."[122] The scope of SURVIAC's work includes "the survivability of allied and other non-adversary systems to threat weapons as well as the effectiveness of U.S. weapons against foreign systems."[123] The SURVIAC's technical task areas include survivable conventional force requirements; survivability technologies; optimizing survivability and lethality; live fire testing; methodology advancement; and support of combat operations.[124] Other areas of interest to SURVIAC include acquisition; detection; tracking; fuzing characteristics; countermeasures and counter-countermeasures; terminal effects; physical and functional characteristics; design, performance, and operational information; acoustics; infrared; optical, electro-optical and radar signatures; combat damage and repair; and probability of kill given a hit (pk/h) functions. SURVIAC is located at Wright-Patterson Air Force Base and is sponsored by the Joint Logistics Commander's Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS) and Munitions Effectiveness (JTCG/ME).

8. Weapon Systems Technology Information Analysis Center

The Weapon Systems Technology Information Analysis Center (WSTIAC) "provides the DoD and user communities with timely and authoritative information on key R&D concepts, results, and trends; applications and processes; and assessment of international R&D technology."[125] WSTIAC accomplishes this through the monitoring and extraction of information relevant to conventional and directed energy weapon systems technology. Technical areas of interest include military systems and supporting equipment; instrument and seeker development and test; manufacturing process development; system and subsystem simulation; development of computational techniques and hardware; control actuators and power sources; sensors for gathering and updating information; aerodynamic and reaction jet control devices; inertial components

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122 "SURVIAC's Mission," Survivability/Vulnerability Information Analysis Center website, http://www.bahdayton.com/surviac/mission.htm.

123 Ibid.

124 "Technical Area Tasks," Survivability/Vulnerability Information Analysis Center website, http://www.bahdayton.com/surviac/tat.htm.

125 "Mission," Weapon Systems Technology Information Analysis Center website, http://www.iitri.org/About/Wstiac_Mission.html, 14 June 2001.

and system developments; guidance aided fuzing; energy management for navigation law profiles; special test equipment and techniques; theoretical performance computations; analytical test techniques; component design criteria; operational serviceability; maintenance and logistics equipment; training systems; specialized RDT&E systems; models, simulations, and basic science and technology activities; environmental protection; and materials areas specifically related to conventional and directed energy weapon systems technology. Sponsored by DITC, WSTIAC is located in Alexandria, Virginia, and operated by IIT Research Institute.

9. Infrared Information Analysis Center

Originally established in 1954 at Willow Run Laboratories, the Infrared Information Analysis Center (IRIA) is now an IAC. "IRIA's mission is to collect, analyze, and disseminate information on infrared and electro-optical (IR/EO) technology with an emphasis on military applications."[126] In fulfilling its mission, the IRIA administers the following symposia: Missile Defense Sensors, Environments and Algorithms; Active EO Sensors; Passive Sensors; Camouflage Concealment and Deception; Materials; National Symposium on Sensor & Data Fusion; Detectors; Infrared Countermeasures; Battlefield Acoustics and Seismic Sensing; MSS 5th International; and Tri-Service Radar. Subject coverage in its electro-optical technology area includes sources of electromagnetic radiation; radiation characteristics of natural and human-made targets; optical properties of materials; detection materials and elements; optical systems and components; detector and system coolers; atmospheric absorption, emission, and scattering; search, homing, tracking, ranging, countermeasures, reconnaissance; and other military infrared and laser systems. IRIA is sponsored by DTIC and "monitored by" the Associate Director for Science and Technology, Army Night Vision and Electronic Sensors Directorate.

10. Chemical Propulsion Information Agency

The Chemical Propulsion Information Agency (CPIA) has been an IAC since 1964. The CPIA's responsibilities are threefold: 1) "the acquisition, compilation, analysis, and dissemination of information and data pertinent to chemical, electrical, and nuclear propulsion technologies;" 2) "technical and administrative support to the Joint Army-Navy-Air Force (JANNAF) Interagency Propulsion Committee;" and

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126 "About IRIA," Infrared Information Analysis Center website, http://www.iriacenter.com/iriaweb.nsf/About%IRIA?OpenPage.

3) performing "technical area tasks (TATs) relevant to missiles, space, and gun propulsion technology."[127] The scope of the CPIA operations includes all science and technology information associated with hardware systems, components and technologies for missile, space and gun propulsion. The Johns Hopkins University, Whiting School of Engineering, operates CPIA in Columbia, Maryland; however, its contract and administrative management responsibilities reside with the Defense Electronics Supply Center and DTIC, respectively.

[127] Chemical Propulsion Information Agency (Brochure), http://www.cpia.jhu.edu/About/aboutcpa.html.

APPENDIX A
UNDERGRADUATE PROGRAMS IN SYSTEMS ENGINEERING

CONTENTS

UNDERGRADUATE PROGRAMS IN SYSTEMS ENGINEERING[1]

Course requirements and other information about undergraduate programs in systems engineering may be found in this appendix. "Year-long" projects or theses are two semesters in length.

A. DISCIPLINE-CENTRIC PROGRAMS

Discipline-centric programs are defined as "basic and advanced level programs leading to a bachelors or higher degree in systems engineering," according to Wolter J. Fabrycky.[2]

1. George Mason University

Location: Fairfax, Virginia

Degree Offered: Bachelor of Science in Systems Engineering

Degree Requirements:

- Three courses in systems modeling, one modeling lab
- One course each in systems engineering management, software engineering, optimization, operations research, decision/risk analysis, systems design, and human factors engineering
  - Spring 2004 Special Topics course: Systems Architecture
- Five-course specialization in any of the following technical areas: systems engineering of software-intensive systems; systems engineering of network and communications systems; economic systems design; systems engineering of environmental and infrastructure systems; systems modeling and performance; transportation systems
  - Can earn a certificate/minor in Transportation Systems
- Year-long senior design project and a one-semester senior seminar

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[1] Unless otherwise specified, all programs have general-education, humanities/social science, and written/oral communication requirements, along with mandatory introductory sequences in calculus, physics, chemistry, and courses in engineering fundamentals, differential equations, and algebra (matrix/linear).

[2] Wolter J. Fabrycky, "Systems Engineering Academic Program Data Bases," paper presented to the Academic Forum, International Council on Systems Engineering, 29 July 2002.

2. George Washington University

Location: Washington, DC

Degree Offered: Bachelor of Science in Engineering Management and Systems Engineering[3]

Degree Requirements:

- Seven courses in operations research (distributed among simulation, modeling, and quality assurance)
- Six courses in computer science (drawn from software engineering, programming, data structures and database design, plus a team software project)
- One class in engineering economics
- Four "professional electives" that are to be focused in one of the following fields: civil engineering, computer science, economics, electrical engineering, engineering management, finance, management, mathematics, mechanical engineering, naval reserve officer training corps, risk management, or statistics.
- An internship in each of the third and fourth years

3. Oakland University

Location: Rochester, Michigan

Degree Offered: Bachelor of Science in Systems Engineering

Degree Requirements:

- Ten engineering core courses, focusing on systems engineering, probability and statistics, general engineering, thermodynamics, statics/dynamics, linear systems, digital logic/microprocessors, electrical circuits
- Eight to 10 courses within three specialty tracks: automotive mechatronic systems, dynamic systems and controls, and manufacturing
  - Automotive Mechatronics
    - Coursework drawn from system design, electrical engineering, mechanical engineering
  - Dynamic Systems and Controls
    - Coursework drawn from electrical engineering and mechanical engineering
    - One systems-engineering control sequence

[3] A Medical Preparation Option, which prepares students for medical school, as well as dual-degree options (with a Master of Science in systems engineering, engineering management, or economics) are available.

    - Manufacturing
        - Coursework focuses on computer science (programming, computation theory, algorithms, software engineering, operating systems, and systems design), along with simulation, computer-aided design, systems engineering, probability and statistics, and systems optimization
- Two track-specific electives
- One free elective
- One-semester senior project or year-long senior design project

4. University of Arizona

Location: Tucson, Arizona

Degree Offered: Bachelor of Science in Systems Engineering

Degree Requirements:

- Seventeen specific departmental courses (distributed among engineering economics, systems design, operations research, modeling, simulation, sophomore and senior colloquia, experiment design, and engineering probability and statistics)
- Five technical electives covering engineering design or science topics and one non-departmental elective

5. University of Arkansas, Little Rock

Location: Little Rock, Arkansas

Degree Offered: Bachelor of Science in Systems Engineering

Degree Requirements:

- Core systems engineering courses focus on modeling, circuits and systems, probability/statistics, optimization methods, and decision analysis
    - Emphasis on design; most of the "systems" courses have a laboratory component
- One course each in C/C++ programming, economics, and organizational behavior
- One upper-level mathematics elective
- Three systems engineering electives
- Year-long senior design project

- Tracks:
  - Computer Systems
    - Coursework emphasizes computer architecture, operating systems, discrete systems, computer networks, software engineering, and microprocessor systems
  - Telecommunications
    - Coursework focuses on signals and systems, systems simulation, electromagnetics and antennas, computer networks, communication systems
    - Electives:
      - One elective in telecommunications
      - 3 additional systems engineering electives

6. University of Pennsylvania

Location: Philadelphia, Pennsylvania

Degree Offered: Bachelor of Science in Engineering in Systems Science and Engineering

Degree Requirements:

- Courses in operations research, systems optimization and design, computer-aided design, project management, engineering economics, and systems control.
- Three non-departmental electives
- Six courses within a field of application focus: Computer Systems, Environmental Systems, Manufacturing Systems, Transportation Systems, Civil Infrastructure Systems, Information and Telecommunications Systems, Service Systems, Economic and Financial Systems, Health Care Systems, or Military Defense Systems
- Year-long senior design project

7. University of Virginia

Location: Blacksburg, Virginia

Degree Offered: Bachelor of Science in Systems Engineering

Degree Requirements:

- Courses in data/information engineering; systems evaluation and design; simulation; applied analysis with databases; network modeling and design; human-machine interface; business evaluation/economic modeling; and systems-engineering concepts
- One advanced science elective, sophomore year

- Junior and senior year electives, distributed as follows:
  - Application electives (three courses) within the following areas: Biomedical Systems; Communications Systems; Computer and Information Systems; Control Systems; Economic Systems [4]
  - Non-departmental (three courses)
  - Technical (two courses)
  - Systems Engineering Design Colloquium (two semesters)

8. Washington University

Location: St. Louis, Missouri

Degree Offered: Bachelor of Science in Systems Science and Engineering[5]

Degree Requirements:

- Courses on engineering probability, linear dynamic systems, control-systems design, numerical methods, and operations research mathematics
- Two laboratory courses — one in digital process control and the other in systems engineering
- Five courses in the focusing on engineering design, 10 on engineering science
- Four departmental electives and four engineering-concentration electives
  - Electives under the engineering concentration are drawn from the departments of chemical engineering, civil engineering, mechanical engineering, and electrical engineering; can concentrate in computer science, economics, mathematics, physics, or pre-medicine, with advisor approval
- One-semester senior design project

B. DOMAIN-CENTRIC PROGRAMS THAT INCLUDE SYSTEMS IN THE MAJOR

Domain-centric programs are defined as "basic or advanced level programs leading to a bachelors, masters, or doctoral degree with the major designated as X and Systems Engineering, Systems and X Engineering, etc," according to Fabrycky.[6]

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[4] The application electives may be chosen from Energy and Environmental Systems; Financial Systems; Human Factors; Intelligent Transportation Systems; Management Systems; Mathematical Systems; self-designed.

[5] The Bachelor of Science can be combined with a Master of Science in Systems Science and Mathematics, or with a minor in Robotics.

[6] Dr. Wolter Fabrycky, "Systems Engineering Academic Program Data Bases."

1. Auburn University

Location: Auburn, Alabama

Degree Offered: Bachelor of Industrial and Systems Engineering

Degree Requirements:

- Courses on mechanics fundamentals, occupational safety and ergonomics, engineering statistics, object-oriented programming; engineering economics, simulation, operations planning, quality control, electrical engineering fundamentals, and manufacturing systems and processes
- Two courses in operations research
- One "professional practice" seminar
- Three departmental (Industrial and Systems Engineering and General Engineering) electives and one technical elective
  - General Engineering electives available are Thermodynamics (two courses), Statics, Mechanics of Materials, Dynamics, Industrial Instrumentation, Materials Engineering, and Statics and Dynamics
- Senior design project

2. Case Western Reserve University

Location: Cleveland, Ohio

Degree Offered: Bachelor of Science in Engineering with a major in Systems, Control, and Industrial Engineering

Degree Requirements:

- Core courses emphasize computer programming, circuits and instrumentation, computer organization and logic design, statics and material strength, signals and systems, simulation, control engineering; thermodynamics, optimization, and engineering economics/decision-making
- Six electives
  - One in either Signal Processing or Communications
  - Remainder drawn from the areas of Dynamic Systems and Control; Complex Systems Analysis; Manufacturing, Industrial Automation, and Operations Systems; and Information Systems[7]
- Freshman Engineering Service Project (optional)
- Senior year: engineering seminar and year-long senior design project

[7] Courses in all of these areas emphasize (dynamic systems) modeling, data acquisition and (feedback) control, systems analysis, decision-making, design, and specific systems.

3. Kansas State University

Location: Manhattan, Kansas

Degree Offered: Bachelor of Science in Industrial and Manufacturing Systems Engineering

Degree Requirements:

- Engineering Assembly, a zero-credit course every semester that provides "an opportunity to learn about various companies and their products and operations" through a series of monthly seminars where "practicing industrial engineers make presentations to the students"[8]
- Industrial Engineering and Manufacturing Systems Engineering program options
  - Industrial Engineering option
    - Core classes on programming in C; engineering graphics; accounting; engineering materials; probability and statistics; industrial project evaluation; industrial ergonomics; operations research; electrical circuits and controls; statics and dynamics; industrial plant studies; statistical quality control; product planning and inventory control; industrial simulation; industrial management; and layout design of industrial facilities.
    - Three departmental electives
    - Year-long senior design project
  - Manufacturing Systems Engineering option
    - Core curriculum is the same as above, with addition of coursework in manufacturing systems engineering; industrial ergonomics; product and process engineering; manufacturing systems design analysis; manufacturing information systems; and computer-aided manufacturing
    - Two departmental electives, to be drawn from engineering science (*e.g.*, robotics, operations research) and from engineering design (for example, occupational safety engineering, factory automation, and work environments)

4. North Carolina Agricultural and Technical University

Location: Greensboro, North Carolina

Degree Offered: Bachelor of Science in Industrial and Systems Engineering

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[8] *Kansas State University 2002-03 Course Catalogue.*

Degree Requirements:

- Courses in computer programming; engineering economics; industrial production processes; information technology; materials science; methods engineering; engineering statistics; quality assurance; operations research; automation and production systems; human factors engineering; production control; experiment design; facilities design; statics/material mechanics; discrete-event simulation; computer-aided design and manufacturing; thermodynamics; electrical circuits and systems; and systems integration
- Sophomore seminar on engineering leadership, a junior seminar on global issues, and two senior seminars (one on ethics, the other on general topics)
- Two technical electives focusing on such topics as robotics, industrial information systems, materials handling systems design, industrial biomechanics, project management, risk analysis, and human-machine systems
- Two non-technical (math and history) electives
- One-semester senior design project

5. Ohio University

Location: Athens, Ohio

Degree Offered: Bachelor of Science in Industrial and Manufacturing Systems Engineering

Degree Requirements:

- Coursework on statics, materials science, systems engineering, engineering economics, engineering statistics, work measurements, facilities design, computer methods, operations research, inventory and manufacturing control, quality control and reliability, information systems engineering, engineering drawing, engineering materials, electrical engineering, thermodynamics, and industrial computer applications
- Two-course sequences in both industrial plant design and systems design
- Electives, distributed as follows:
  - One introductory macroeconomics class
  - One business elective
  - Four non-departmental electives and five departmental electives
    - Electives focus on manufacturing systems, materials handling systems engineering, experiment design, cost engineering, systems engineering, microprocessor applications, manufacturing data systems, systems modeling and manufacturing, project management, inventory and manufacturing control, digital computer systems, and applied mathematical programming

6. Ohio State University

Location: Columbus, Ohio

Degree Offered: Bachelor of Science in Industrial and Systems Engineering

Degree Requirements:

- Courses in engineering graphics, engineering mechanics, operations research, systems and facilities design, cost accounting, human-factors engineering, production systems design, statistical process control, project management, experiment design, materials science and engineering, linear programming, optimization, computer simulation, work measurement, inventory control, methods engineering, and statistical methods.
- Two-semester seminar in industrial practice in systems design
- Nine professional electives
  - Electives are concentrated, first, in one of the following areas: manufacturing, human factors, operations research, or industrial engineering, and then are distributed among industrial design, mathematics, physics, psychology, business management, biology, chemistry, electrical engineering, geodetic/geologic science, and statistics

7. San José State University

Location: San José, California

Degree Offered: Bachelor of Science in Industrial and Systems Engineering

Degree Requirements:

- Core curriculum focuses on computer engineering, design and graphics, circuit analysis, engineering of economic systems, manufacturing engineering/processes, computer-integrated manufacturing, work methods design/measurement, statistical process control, engineering probability/statistics, operations planning/control, experiment design, engineering management, systems simulation, operations research, engineering reports, software engineering
- Three technical electives, drawn from the fields of software systems engineering, semiconductors/manufacturing, human factors/ergonomics, transportation/traffic management, business management, packaging
- Two-semester senior design project in industrial engineering

8. University of Alabama, Huntsville

Location: Huntsville, Alabama

Degree Offered: Bachelor of Science in Engineering with an Industrial and Systems Engineering Option

Degree Requirements:

- Core courses focus on computer methods in engineering, engineering graphics, operations research, materials mechanics, manufacturing processes, ergonomics, management systems analysis, production and inventory control, electrical circuit analysis, engineering probability and statistics, statistical quality control, and systems simulation
- One course in manufacturing systems/facilities design and two in systems analysis and design
- Electives, distributed as follows:
  - Engineering design (one course)
  - Departmental electives (two)
  - Technical elective (one)

9. University of Central Florida

Location: Orlando, Florida

Degree Offered: Bachelor of Science in Industrial Engineering

Degree Requirements:

- Coursework in dynamics and statics, engineering probability and statistics, electrical engineering, materials science, computer graphics, human factors engineering, manufacturing engineering, computer applications, cost engineering, operations research, industrial facility planning and design, systems simulation, engineering management, thermodynamics, systems analysis and design, and quality engineering.
- One technical elective
- One-semester senior design project

10. University of Florida

Location: Gainesville, Florida

Degree Offered: Bachelor of Science in Industrial and Systems Engineering

Degree Requirements:

- Core curriculum emphasizes engineering graphics, industrial/systems engineering, matrix and numerical methods, engineering mechanics/statics,

engineering economics, financial accounting, facilities planning and materials handling, microprocessors, thermodynamics, materials, industrial quality control, decision support systems, and simulation.

- One course each in differential engineering and in computer programming for engineers
- Two-course sequences in mathematical statistics, in operations research, in human factors/ergonomics, and in analysis/design of production and distribution systems
- Eleven credits (four or five courses) of technical electives that are drawn from one of the following fields: engineering, computer science, mathematics, statistics, physics, or business

11. University of Michigan, Dearborn

Location: Dearborn, Michigan

Degree Offered: Bachelor of Science in Engineering in Industrial and Systems Engineering

Degree Requirements:

- Coursework is distributed among four areas: Distribution Requirements, Basic Preparation Requirements, Professional Requirements, and Concentration.
  - Distribution Requirements
    - Seven to eight courses in English composition, humanities/social science, and introductory macroeconomics
  - Basic Preparation Requirements
    - Calculus, chemistry, and physics sequences
    - One course each in introductory engineering and computer graphics
    - A three-class core focused on thermodynamics, applied mechanics, and principles of engineering materials
  - Professional Requirements
    - Classes on operations research, manufacturing processes, engineering economics/decision analysis, human factors/ergonomics, simulation in systems design, information-systems design, statistical quality control, facilities design, and production/inventory control systems
  - Concentration
    - Five courses in either manufacturing systems, information systems, or a self-designed, advisor-approved concentration
    - Two additional electives
- One-semester senior design project

12. University of San Diego

Location: San Diego, California

Degree Offered: Bachelor of Science in Industrial and Systems Engineering

Degree Requirements:

- Classes in programming, thermodynamics, engineering economics, materials engineering, electrical engineering principles, engineering statistics, methods analysis, statistical process control, operations research, experiment design, manufacturing processes, production and operations management, human factors engineering, systems simulation, systems design, and facilities planning
- One engineering elective; second-semester freshmen take an engineering design practicum
- One-semester senior design project

13. University of Southern California

Location: Los Angeles, California

Degree Offered: Bachelor of Science in Industrial and Systems Engineering

Degree Requirements:

- Core courses in computer programming, engineering probability, manufacturing processes, statics, engineering statistics, electrical engineering, operations research, human-factors engineering, engineering economics, statistical quality control, discrete systems simulation, accounting, and production control
- Two-course introductory sequence in industrial and systems engineering
- One course in introductory microeconomics
- One departmental elective
- Two non-departmental electives
- Senior seminar
- Year-long senior design project

14. Virginia Polytechnic Institute and State University (Virginia Tech)

Location: Blacksburg, Virginia

Degree Offered: Bachelor of Science in Industrial and Systems Engineering

Degree Requirements:

- Freshmen and sophomores:
  - Introductory industrial and systems engineering courses, basic chemistry and physics courses, one class each on differential equations and on multivariate calculus, and some general education and humanities/writing/oral communication requirements
- Juniors and seniors:
  - Courses on statics and dynamics, engineering economics, computer-aided design, programming in C++, product planning and inventory control, statistical quality control, manufacturing processes, engineering statistics, operations research, materials engineering, human factors and work methods engineering, facilities planning and materials handling, industrial ergonomics, and computer simulation
- Electives:
  - Two engineering science electives, from among hydraulics, force structures, thermodynamics, robotics, prototyping, and others
  - Three humanities/social science electives
  - Minimum of two departmental technical electives
    - Technical electives examine management theory, computer-aided manufacturing, industrial quality control, logistics, and ergonomics/work physiology
  - Two additional technical electives, drawn from statistics, engineering (including industrial and systems engineering), chemistry, physics, computer science, and mathematics
  - Two non-technical electives
- Senior seminar on industrial management and a year-long senior design and management project

15. Wichita State University

Location: Wichita, Kansas

Degree Offered: Bachelor of Science in Industrial Engineering

Degree Requirements:

- One class each in statics, circuits, engineering economics, and thermodynamics.
- Other required courses focus on programming in C, materials engineering, manufacturing methods, engineering graphics, work systems and industrial ergonomics, probability and statistics, operations research, production systems, statistical quality control, facilities planning, and systems design and simulation

- Electives:
  - Three technical, which can be drawn from the areas of engineering, business, computer science, or psychology (*e.g.*, "industrial psychology" and "human factors psychology")
  - Five non-technical
- Engineering seminar
- Year-long senior design project

16. Youngstown State University

Location: Youngstown, Ohio

Degree Offered: Bachelor of Science in Industrial and Systems Engineering

Degree Requirements:

- Classes in engineering economics, engineering statistics, materials science, systems analysis and design, methods engineering, statics, dynamics, systems simulation, manufacturing processes, statistical quality control, manufacturing automation, operations research, and circuits.
- Two departmental electives
- One nondepartmental, engineering elective
- Year-long senior design project

APPENDIX B
GRADUATE PROGRAMS IN SYSTEMS ENGINEERING

CONTENTS

GRADUATE PROGRAMS IN SYSTEMS ENGINEERING

Course requirements and other information about graduate programs in systems engineering may be found in this appendix. Where applicable, thesis and non-thesis options are described. "Year-long" projects or theses are two semesters in length.

A. DISCIPLINE-CENTRIC PROGRAMS

Discipline-centric programs are defined as "basic and advanced level programs leading to a bachelors or higher degree in systems engineering," according to Dr. Wolter Fabrycky.[1]

1. Boston University

Location: Boston, Massachusetts

Degree Offered: Doctor of Philosophy in Systems Engineering[2]

- Areas of specialization available are systems engineering, biomedical engineering, electrical engineering, computer engineering, mechanical engineering, manufacturing engineering

Degree Requirements:

- For post-bachelor's degree students:
  - Approximately 16 courses — five to eight of which are "structured," or required[3]
  - Minimum of four dissertation/research courses
- For post-master's degree students:
  - No core curriculum specified, but must take eight courses and two dissertation/research courses

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1 Fabrycky, "Systems Engineering Academic Program Data Bases," paper presented to the Academic Forum, International Council on Systems Engineering, 29 July 2002.

2 This is an interdisciplinary program, as students are admitted to, and do coursework in, one of the four departments in the College of Engineering (Aerospace and Mechanical; Biomedical; Electrical and Computer; Manufacturing) before taking qualifying exams and writing a dissertation.

3 The "structured" courses for post-bachelor's doctoral students in the Biomedical Engineering department, for example, are two graduate physics and biology courses and three graduate classes in biomedical engineering.

2. George Mason University

Location: Fairfax, Virginia

Degrees Offered: Master of Science in Systems Engineering and Doctor of Philosophy in Systems Engineering

Degree Requirements:

- Master of Science in Systems Engineering
  - Three core courses focusing on systems design and integration, systems definition/cost modeling, and management
  - Two methods courses
    - Systems architecture for large-scale systems is a methods course in the following tracks: systems engineering methods, systems engineering for computer-based systems, and advanced transportation systems
  - Three to four special elective courses
    - Elective tracks: advanced transportation systems, systems engineering of computer-based systems, command, control, communications and intelligence, systems engineering methods, system management, and telecommunications systems
      - Courses in all six tracks focus on operations research to some degree, with the command, control, communications and intelligence and telecommunications tracks placing the most emphasis on it
      - Engineering and design are emphasized in Advanced Transportation Systems and Systems Engineering of Computer-Based Systems courses
      - The Systems Engineering Methods track's curriculum is methods, theory, and programming-based
      - Management, systems engineering for design, and systems architecture are the foci for Systems Engineering Management electives
      - Systems Architecture for Large-Scale Systems is an elective in the Command, Control Communications, and Intelligence track
  - Thesis or project
- Doctor of Philosophy in Systems Engineering
  - Coursework drawn from the Department of Systems Engineering and Operational Research is computational in focus, with some courses on systems integration and theory

3. George Washington University

Location: Washington, DC

Degrees Offered: Master of Science in Systems Engineering, Accelerated Master of Science in Systems Engineering (also called Accelerated Master of Science in Engineering Management, Master of Science in Engineering Management, Doctor of Science in Engineering with concentration in Systems Engineering

Degree Requirements:

- Master of Science in Systems Engineering
  - Four core courses focused on systems engineering, management of technical organizations, problem-solving/decision-making, and engineering economics
  - Six depth courses emphasizing operations research, systems engineering, engineering management, systems analysis, and systems simulation
  - Two electives
- Accelerated Master of Science in Systems Engineering (also called Accelerated Master of Science in Engineering Management)
  - Offered at Virginia campus, 12-month program meeting on Saturdays
  - 12 courses, covering systems engineering, operations research, statistics, engineering/project management, decision making, systems analysis, engineering economics
- Master of Engineering Management
  - Core same as that for Master of Science in Systems Engineering
  - Depth courses focused on management
- Doctor of Science in Engineering with concentration in Systems Engineering
  - Core coursework designed in conjunction with faculty advisor

4. Iowa State University

Location: Ames, Iowa

Degree Offered: Master of Engineering in Systems Engineering

Degree Requirements:

- Program flexible in terms of electives and areas of specialization
- Two core courses in systems engineering: "Systems Engineering and Analysis" and "Applied Systems Engineering"
- Remaining coursework distributed among engineering electives (two courses), an area of specialization (three courses), and non-engineering electives (two courses)

- Electives:
  - Systems engineering electives (two classes)
  - Non-engineering electives (two courses), drawn from business, economics, computer science, mathematics, and statistics
- One-semester thesis

Other Information:

- Offered through division of Engineering Distance Education
- Program aimed at practicing engineers
- Another core course, "Avionics Systems Engineering," is also available, but it is only open to employees of Rockwell Collins

5. Johns Hopkins University

Location: Baltimore, Maryland

Degree Offered: Master of Science in Systems Engineering

Degree Requirements:

- Eight core courses, focused on systems engineering and design, test, and evaluation
- Two electives, drawn from "relevant" courses in technical management, applied biomedical engineering, applied physics, computer science, electrical engineering, environmental engineering, and information systems/technology

Other Information:

- Two-course concentration option in project management available

6. Massachusetts Institute of Technology

Location: Cambridge, Massachusetts

Degrees Offered: Master of Science in Systems Design and Management; Master of Science in Engineering Systems; Doctor of Philosophy in Engineering Systems

Degree Requirements:

- Master of Science in Engineering Systems
  - Core is at least four courses in each of the following areas: Systems Theory, Design, and Architecture; Socio-Technical/Enterprise Systems; Research Methods
    - Systems Theory, Design, and Architecture core focuses on systems theory, systems architecture, systems engineering, program management, product design and development
    - Socio-Technical/Enterprise Systems classes drawn from aerospace design, engineering systems, environmental systems,

information systems/enterprise resource systems/e-business, lean enterprise systems, manufacturing process and systems, general social systems, product design, software engineering, technology applications, logistics and supply chain
        - Overarching focus is on design and integration
      - Research methods classes focus on microeconomics, econometrics, probability and statistics, operations research, optimization, linear programming, system dynamics, simulation, engineering system analyses, social science research methods
    - Depth concentration is three courses in one of the above three areas
    - Thesis required
- Doctor of Philosophy in Engineering Systems
  - Core same as above
  - Technical Electives (specialty area), 48 units minimum
    - Technical specialty areas available: aeronautics and astronautics; chemical engineering; civil and environmental engineering; electrical engineering and computer science; materials science and engineering; mechanical engineering; nuclear engineering; ocean engineering
      - Within areas/schools above, can focus on space systems, air transportation systems; communications systems; information systems; freight transportation systems; supply chains; manufacturing systems
  - Minor in at least one engineering discipline or other appropriate area of technical expertise (three courses)
  - Doctoral research seminar
  - Dissertation

7. National Technological University

Location: Fort Collins, Colorado

Degree Offered: Master of Science in Systems Engineering

Degree Requirements:

- Minimum of 11 courses: 5 core courses and two (each) distributed among depth, breadth, and electives courses:
  - Core sequence drawn from one of the following sub-areas: systems engineering principles and processes, modeling analysis, cost analysis, systems optimization, systems reliability, and systems management.
    - "Systems Architecting" is an elective in the systems engineering principles and processes core sub-area; class taught at the University of Mississippi-Rolla

- Depth courses chosen from the sub-areas of systems engineering methodology, software management/psychology/control methods, logistics and acquisitions systems engineering, and systems engineering design
- Breadth electives selected from the areas of aeronautics and aerospace, electronics, information systems, and telecommunications
- Two additional electives from any area

Other Information:

- Offered via distance learning
- Classes in integration and testing, modeling and simulation, and engineering management/risk management available

8. Oakland University

Location: Rochester, Michigan

Degrees Offered: Master of Science in Systems Engineering, Doctor of Philosophy in Systems Engineering

Degree Requirements:

- Master of Science in Systems Engineering
  - Approximately 10 courses
  - Must choose from one of five tracks:
    - Dynamic systems and control, manufacturing systems, robotics, system modeling and computer simulation, and general systems engineering
    - All tracks require coursework distributed among mathematics (one to two courses), track-specific topics (at least three courses), "depth areas" such as optimization or specific systems, *e.g.*, "Intelligent Systems" and "Control Systems" (two courses)
    - Up to two electives
  - Thesis optional

- Doctor of Philosophy in Systems Engineering
  - Three to four courses in a systems concepts core in either the Continuous Systems or the Discrete Systems track[4]
  - "Discipline-specific" courses in the selected track
    - Available options are robotics, mechatronics, signal/image processing, manufacturing techniques, optimization, electromagnetics, control (intelligent/adaptive and digital), computer-integrated manufacturing, computer-aided design, software systems, artificial intelligence, software engineering, parallel processing, data mining, and microprocessor systems
  - May also specialize in computer systems, control engineering and design systems, electrical engineering systems, manufacturing process and systems, or mechanical engineering systems

9. Old Dominion University

Location: Norfolk, Virginia

Degree Offered: Master of Engineering in Systems Engineering

Degree Requirements:

- Seven-course core curriculum focused on management, systems analysis, integration, processing, engineering and design
- Three electives, chosen from among operations research, logistics/supply chain management, systems design, systems dynamics, modeling, simulation, economic analysis, systems analysis, cost engineering, risk analysis, reliability/maintainability, and engineering design

10. Pennsylvania State University, Great Valley

Location: Malvern, Pennsylvania

Degree Offered: Master of Engineering in Systems Engineering

Degree Requirements:

- Four "modules" of three classes each: one skill-based module, one systems-engineering module, and two electives modules
  - Skill-based module courses focus on project management, communication skills, and design and innovation

[4] Continuous Systems courses focus on signals/systems analysis, continuum mechanics, and mathematical analysis). Discrete Systems classes examine computer simulation, computational theory, and discrete mathematics.

- Systems-engineering module courses focus on engineering analysis, general systems engineering, and systems optimization
- Electives must be in two areas selected from the following fields: mechatronics/robotics, manufacturing systems, fluid thermal science, telecommunications, industry statistics, innovation and research, intelligent systems, decision support systems, control systems, engineering mathematics, and electrical, environmental, industrial, mechanical, or software engineering
- Professional paper or capstone course

- Proposed Doctor of Engineering in Systems and Software Engineering
  - Planned as a part-time program "intended for working engineers, scientists, and technologists seeking a deeper understanding of software and systems engineering, professional engagement in applied R&D, career advancement, college-level teaching, and/or scholarly research"
  - Would require approximately 25 courses, plus 21–30 credits (~7–10 course units) thesis research and dissertation preparation

11. Polytechnic University

Location: Melville, Long Island, New York

Degree Offered: Master of Science in Systems Engineering

Degree Requirements:

- Three core courses chosen from among matrix theory, signals and systems, feedback control, linear systems, probability, and statistical inference
- Two, two-course, year-long sequences in any of the following fields: materials science, electronics, and power, systems and information science, computer science, and fields and waves
  - One sequence should be on an electrical engineering topic (e.g., signals/systems, systems theory)
- Five to seven electives, drawn from quality control, quality engineering, applied mathematics, mathematical theory, statistical analysis, operations and technology management, systems, and manufacturing systems engineering

12. Portland State University

Location: Portland, Oregon

Degree Offered: Master of Engineering in Systems Engineering

Degree Requirements:

- Four core courses, focusing on systems engineering approach, hardware and software integration, operations research, and modeling and simulation

- Four electives
  - Drawn from departments of Civil Engineering, Computer Science, Electrical and Computer Engineering, Engineering Management, Mechanical Engineering, Manufacturing Engineering, Software Engineering, and Systems Science. Systems Engineering classes may also be chosen for elective coursework[5]
- Student-advisor integrative workshop
  - Geared towards creating the student's Web-based portfolio, which outlines the individualized program of study pursued and provides an opportunity for the student to tie together his or her knowledge and understanding of theory, practice, and process
- Internship or project

13. Southern Methodist University

Location: Dallas, Texas

Degrees Offered: Master of Science in Systems Engineering, Executive Master of Science in Systems Engineering[6]

Degree Requirements:

- Master of Science in Systems Engineering[7]
  - Five core courses in systems analysis methods, systems engineering process and analysis, optimization, risk management, and systems integration and testing
  - Five courses in either of four tracks: systems engineering and design, systems engineering technology, logistics and supply chain management, systems engineering application
    - Systems Engineering and Design Track:
      - Classes drawn from computer science, operations research, manufacturing engineering, thermodynamics, systems analysis and design, and telecommunications
    - Systems Engineering Technology Track:
      - Courses focus on systems engineering design, software engineering, systems engineering management, reliability engineering, and logistics systems engineering

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[5] Courses available as electives are "Logistics Engineering," "Requirements Engineering," "Reducing Risk in Decision Making," "Reliability and Maintainability," and "Manufacturing System Simulation."

[6] A Bachelor of Science in systems engineering is proposed. A Doctor of Philosophy in applied science with a major in systems engineering is pending approval.

[7] Program expanded as of January 2003.

        - Logistics and Supply Chain Management Track:
            - Three courses in systems reliability engineering, logistics systems engineering, production and operations management
            - Two electives, drawn from statistical quality control, reliability engineering, operations research models, economic decision analysis, optimization models
        - Systems Engineering Application Track:
            - Five electives in one or more fields of concentration – computer science and engineering, electrical engineering, engineering management, environmental engineering, information engineering and management, manufacturing engineering, mechanical engineering, operations research, software systems engineering, systems engineering, telecommunications
    - Two other electives in business, physics, economics, chemistry, statistics, math, or other engineering programs
- Executive Master of Science in Systems Engineering[8]
    - Ten courses on systems engineering processes, methods, optimization and analysis, logistics and software systems engineering, design, risk management, and systems engineering tools
        - Classes given over five monthly Friday-Saturday sessions

14. Southern Polytechnic State University

Location: Marietta, Georgia

Degrees Offered: Master of Science in Systems Engineering, Master of Science in Systems Engineering with Civil Concentration

Degree Requirements:

- Master of Science in Systems Engineering
    - Six core courses, covering systems engineering, technical/innovation management, systems analysis/design, system architecture, engineering economics, development/management of verification programs, reliability and sustainability
    - One workshop, either "Systems Development Workshop" or "Systems Engineering Workshop"
    - Two electives, chosen from among "Modeling and Simulation," "Advanced Configuration Management," "Process Assessment and Improvement," and "Software Project Management"

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[8] Accelerated 2-year degree program geared toward career professionals. Since January 2003, offered exclusively for employees of Lockheed Martin Aeronautics Company, on-site in Fort Worth, Texas. In 2003 and 2004, will be offered at Lockheed Martin Aeronautics, plus Lockheed-Martin Missile and Fire Control in Dallas and Dallas-area division of Raytheon.

- Two additional electives, drawn from the areas of management, computer science, electrical and computer engineering technology, software engineering, quality assurance, and technical communication

- Civil Concentration option:
  - Six core courses, focusing on systems engineering, technical/innovation management, systems analysis/design, system architecture, engineering economics, development/management of verification programs
  - Four civil engineering courses, on transportation systems planning/design, sustainable development, environmental systems, infrastructure planning/management
  - Civil Systems thesis

Other Information:

- Program offered through the School of Engineering Technology and Management and developed in conjunction with Lockheed Martin Aeronautical Services
- Degree program approved November 2002, formally started September 2003 with evening classes held on a part-time basis
  - Curriculum is essentially Graduate Certificate and Advanced Graduate Certificate curricula (as described in Appendix C) combined, plus two additional electives

15. Stevens Institute of Technology

Location: Hoboken, New Jersey

Degrees Offered: Master of Engineering in Systems Design and Operational Effectiveness, Master of Engineering in Systems Engineering, Master of Engineering with Certificate in Systems Engineering, and Doctor of Philosophy in Systems Engineering[9]

Degree Requirements:

- Master of Engineering in Systems Engineering
  - Four core courses :
    - Two courses in systems effectiveness and design: "Systems Operational Effectiveness and Life-Cycle Analysis" and "System Architecture and Design"
    - Two courses chosen from either project management, decision and risk analysis, or modeling and simulation

[9] There appear to be subtle differences between the Master of Engineering with Certificate in Systems Engineering and the Master of Engineering in Systems Engineering.

- Six electives, distributed according to the following options:
  - Two courses from systems engineering and engineering management and a four-course sequence leading to a specialty certificate
  - Two courses from systems engineering and engineering management and four additional systems engineering electives
- Master of Engineering in Systems Design and Operational Effectiveness
  - Core same as above
  - Specialization in either Systems Design and Architecture or Supportability Engineering and Logistics
    - Systems Design and Architecture classes are design-focused
    - Supportability Engineering and Logistics are management and integration/design-oriented
- Doctor of Philosophy in Systems Engineering[10]
  - Five to 10 courses beyond the master's
  - Dissertation counts for 30–45 credit hours

16. University of Arizona

Location: Tucson, Arizona

Degrees Offered: Master of Science in Systems Engineering, Doctor of Philosophy in Systems and Industrial Engineering

Degree Requirements:

- Master of Science in Systems Engineering
  - Coursework focuses in the areas of computer software engineering, engineering statistics, human performance, optimization, probabilistic modeling and technology, production systems, reliability and quality, and systems theory
  - Thesis option:
    - Thesis or report plus 30 units coursework
  - Non thesis option:
    - 33 units coursework, plus oral exam
- Doctor of Philosophy in Industrial and Systems Engineering
  - Coursework draws on probabilistic models, engineering statistics, optimization, and linear systems theory
- *Other Information*:
  - Programs of study for both programs are tailored to the individual student's needs.

[10] Further information on the doctoral curriculum is unavailable

17. University of Florida

Location: Gainesville, Florida

Degrees Offered: Master of Engineering (Systems Engineering Option), Master of Science (Systems Engineering Option), Doctor of Philosophy in Industrial and Systems Engineering

Degree Requirements:

- Master of Engineering (Systems Engineering Option), Master of Science (Systems Engineering Option)
  - Three-course core is heavily focused on operations research, probability, and statistics
  - Three or more departmental electives, drawn from reliability engineering, operations research, simulation, systems analysis, and engineering economy
  - Unspecified number of free electives, chosen from among management, manufacturing, engineering, and statistics
  - Thesis optional
    - Non-thesis students take a "Project Course" in either the semester of graduation or the semester prior; courses available are "Principles of Manufacturing Systems Engineering," "Digital Simulation Techniques," "Decision Support Systems for Industrial and Systems Engineering," "Web-Based Decision Support Systems for Industrial and Systems Engineering"
      - Can take an independent study with a faculty advisor, in lieu of a Project Course
- Doctor of Philosophy in Industrial and Systems Engineering
  - Three required background courses, covering statistics, engineering economy, and simulation
  - Two computer programming courses (one basic, one advanced)
  - Two non-departmental courses
  - Technical requirements:
    - Technical presentation skills, to be fulfilled via teaching, presenting in the Graduate Seminar course, or enrollment in teaching, education, or communication courses
  - Technical paper
  - Unspecified number of electives in an area of specialization
    - Areas available: linear, combinatorial, and nonlinear/global optimization; supply chain management and e-commerce; financial engineering; manufacturing management; facility layout and location; quality engineering; and stochastic processes

- Graduate Seminar, taken in the fall semester of the second year in the PhD program and in the spring semester of the third year; must present in the latter

18. University of Houston, Clear Lake

Location: Houston, Texas

Degree Offered: Master of Science in Systems Engineering

Degree Requirements:

- Core curriculum of seven courses, which cover systems engineering processes, economics, analysis, and modeling; concurrent engineering; engineering specialty integration; risk management; and software project management
- Electives in either of two options: analysis or management
  - Analytical Option:
    - Two courses available, one in decision analysis and one in human factors engineering
  - Management Option:
    - Two classes offered, one in technology management and one in human-resources management
  - Remaining electives (for non thesis students) are drawn from engineering, science, or math courses
- Thesis option:
  - One elective
  - Year-long thesis (two courses)
- Non thesis option:
  - Three electives
  - Capstone

19. University of Idaho at Idaho Falls

Location: Idaho Falls, Idaho

Degree Offered: Master of Engineering in Systems Engineering; Certificate in Systems Engineering (described in Appendix C)

Degree Requirements:

- Master of Engineering in Systems Engineering
  - Four core courses, which focus on systems design and decision-making, applied systems engineering, and systems requirements
  - A minimum of five electives in one of four areas of emphasis: Statistics; Human/Social Interaction; Modeling; Management
  - One course in systems technology ethics
  - Thesis, project, or comprehensive exam

20. University of Illinois at Urbana-Champaign

Location: Urbana, Illinois

Degree Offered: Master of Science in Systems and Entrepreneurial Engineering; Doctor of Philosophy in Systems and Entrepreneurial Engineering[11]

Degree Requirements:

- Unspecified number of unidentified core courses and electives
- Areas of study available are computer-aided design, optimization, design systems, manufacturing systems, nondestructive test and evaluation, robotics, decision-making, reliability, entrepreneurial engineering, control, systems dynamics and simulation, operations research, management science, and biomechanics
- Thesis

21. University of Maryland, College Park

Location: College Park, Maryland

Degrees Offered: Master of Science in Systems Engineering; Professional Master of Engineering with a systems option

Degree Requirements:

- Master of Science in Systems Engineering
  - Thesis option:
    - Four systems engineering core courses, which focus on principles, design, and engineering
    - Three management courses, which center on financial and contract management, life cycle cost, and quality management
    - Three electives, one of which should be in a specialization area

[11] Programs approved January 2003; the two research degrees are devoted to the integration of engineering and business systems.

        - Fields of specialization available are software systems; computer systems; information systems; distributed systems; control systems; manufacturing systems; process systems; and operations research
            - Course on computer systems (design and architecture) available
    - Non-thesis option:
        - Same core/management course requirements as above
        - Five electives drawn from two of the fields of specialization mentioned above
        - Scholarly paper
        - Comprehensive exam
- Professional Master of Engineering with Systems Option[12]
    - Same core/management course requirements as above
    - Three electives drawn from departments of Business and Management; Computer Science; Electrical Engineering; Civil and Environmental Engineering; Mechanical Engineering; and Reliability Engineering
        - Course on computer systems (design and architecture) available
    - Thesis, paper, or comprehensive examination not required

22. University of Missouri, Rolla

Location: Rolla, Missouri

Degree Offered: Master of Science in Systems Engineering; Certificate in Systems Engineering (described in Appendix C)

Degree Requirements:

- Six core courses
    - One course each in systems architecting, engineering economics, engineering management, and project management
    - Two-course sequence in systems engineering analysis
- Four electives in an area of specialization
    - Areas of specialization available are artificial/computational intelligence/robotics; communications systems; control systems; economic decision analysis; engineering management; flight systems; human factors; information systems/computer architecting; manufacturing systems; multimedia; quality and reliability engineering; software systems; and systems and design optimization
    - Optional thesis

[12] An application- and methods-oriented professional program "designed to assist engineers in the development of their professional careers and to provide the technical expertise needed in the business, government, and industrial environments."

23. University of Pennsylvania

Location: Philadelphia, Pennsylvania

Degrees Offered: Master of Science in Engineering (Systems Engineering); joint Master of Science in Engineering/Master of Telecommunications and Networking program; joint Master of Science in Engineering (Systems Engineering)/Master of Business Administration; Doctor of Philosophy in Electrical and Systems Engineering.

Degree Requirements:

- Master of Science in Engineering (Systems Engineering)
  - Four core courses, emphasizing probability, economic analysis, simulation, and optimization
  - "Focus" component
    - Six courses drawn from the School of Engineering's offerings; may include an independent study or a thesis systems optimization, systems control, logistics, manufacturing, systems analysis, civil engineering, operations management, and operations research
- Doctor of Philosophy in Electrical and Systems Engineering
  - 20 courses, distributed as follows:
    - Two mathematics courses, chosen from mathematics, engineering mathematics, discrete mathematics, statistics
    - Five courses in the major field
    - Two courses in each of the two minor fields
    - Electives, independent study, research/nonresearch courses, and additional major/minor courses to round out the coursework distribution
  - Two-semester teaching practicum
  - Qualifying examination
    - Exam covers linear systems, probability, electromagnetic and optical fields, solid-state physics/devices, communications, networking, optimization, and VLSI/microelectronics

24. University of Southern California

Location: Los Angeles, California

Degrees Offered: Master of Science in Industrial Systems and Engineering; Master of Science in Industrial Systems and Engineering/Master of Business Administration; Master of Science in Systems Architecture and Engineering;

Doctor of Philosophy in Industrial Systems and Engineering; Certificate in Systems Engineering (described in Appendix C)

Degree Requirements:

- Master of Science in Industrial Systems and Engineering
  - Two core courses, focusing on advanced production planning and scheduling and on engineering project management
  - Six departmental electives, one from each of the following areas: systems design; production; systems performance; information systems; quantitative methods
    - Systems Design electives focus on experiment design, quality management, systems engineering theory/practice
    - Production electives focus on computer-aided manufacturing, inventory systems, enterprise systems
    - Systems Performance courses emphasize team management, performance analysis, human factors engineering
    - Information Systems offerings focus on simulation and web-based technology for industrial engineering
    - Quantitative Methods courses center on operations research and linear programming
  - Three advisor-approved electives
- Master of Science in Industrial Systems and Engineering/Master of Business Administration
  - Five systems engineering core courses, focusing on product planning/scheduling, engineering project management, performance analysis, engineering economy, and computer
  - Core Master of Business Administration courses (approximately 15)
- Master of Science in System Architecture and Engineering[13]
  - Three core courses: one each on systems architecting, on engineering economy, and on engineering theory and practice
  - One design experience course chosen from among "Systems Architecture Design Experience," "Elements of Vehicle and Energy Systems Design," and "Software Engineering"
    - Elective coursework distributed among Technical Management, General Technical, and Technical Specialization areas and focused on the design, engineering, and architecture processes

[13] A unique aspect of this master's program, as well as the certificate program, is that all of the required courses are offered through the Distance Education Network in a joint collaboration with the University of Missouri at Rolla.

        - Technical Management and General Technical areas both consist of two required courses and one elective
            - "Systems Architecting B" an available course
        - Technical Specialization area consists of four courses
            - Can specialize in aerospace and mechanical systems; artificial intelligence/neural networks; automation and control systems; communications and signal processing systems; computer and information systems; construction; engineering management systems; manufacturing systems; software process architecture; systems
- Doctor of Philosophy in Industrial and Systems Engineering
    - Two required courses: "Inventory Systems" and "Engineering and Project Management"
    - Four cognate courses in the Industrial and Systems Engineering Concentration, chosen from the areas of operations research/production; engineering/technical management; and manufacturing
    - Three courses in a minor field, outside the department
    - Electives:
        - Four departmental
        - Five to six nondepartmental
    - PhD seminars (two units)
    - Up to three courses of directed research

25. University of Virginia

Location: Charlottesville, Virginia

Degrees Offered: Master of Science in Systems Engineering; Master of Engineering in Systems Engineering; Accelerated Masters in Systems Engineering; Doctor of Philosophy in Systems Engineering

Degree Requirements:

- Master of Engineering in Systems Engineering[14]
    - Four core courses emphasizing engineering, operations research (stochastic systems), modeling, and systems integration

[14] Non-thesis, professional degree program suitable for those who do not already have an engineering background. Can also complete program through Commonwealth Graduate Education Program, a consortium of graduate engineering programs in Virginia that offers graduate engineering education via videoconference.

- Six systems-focused electives
  - System areas available: control, decision, economic, environmental, financial, information technology/communications, intelligent, health care, management, manufacturing, transportation, urban
  - Can also specialize in mathematical/statistical modeling, risk assessment/management, social/ethical dimensions of system design
- Systems Engineering Colloquium, designed to bridge theory and practice

- Master of Science in Systems Engineering[15]
  - Three core courses emphasizing engineering, operations research (stochastic systems), and modeling
  - Four electives centered around a specialization area
    - Areas available same as above
  - Systems Engineering Colloquium
  - Thesis
- Accelerated Masters in Systems Engineering[16]
  - Three core courses, focusing on systems engineering, enterprise analysis/modeling, probabilistic modeling, systems management and integration
  - Unspecified number of electives, drawn from courses in information systems architecture; modeling and simulation; performance analysis; data communication/networks; innovation and technology; data analysis/forecasting; management/government issues
    - Information Technology and mini-MBA tracks available
  - Friday evening seminars after dinner
- Doctor of Philosophy in Systems Engineering
  - Two courses in graduate mathematics
  - Remaining coursework drawn from systems engineering, operations research, and optimization, chosen with faculty approval

26. Virginia Tech

Location: Blacksburg, Virginia

Degrees Offered: Master of Science in Systems Engineering; Master of Science in Industrial and Systems Engineering/*Diplôme de Formation Specialisée in Génie des Systèmes Industriels*; Doctor of Philosophy in Industrial and Systems Engineering

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[15] Research degree.

[16] Program is 11 months long and is designed for business executives and technical professionals; began May 2004.

Degree Requirements:

- Master of Science in Systems Engineering
  - Two-course core, focusing on systems engineering process and on applied systems engineering
  - Four courses in a specialty track
    - Tracks available: electrical engineering, mechanical engineering, industrial engineering, civil engineering, aeronautical engineering, ocean engineering
  - Three electives
    - Two courses in a engineering discipline outside the specialty track
    - One non-engineering course, chosen from among computer science, mathematics, physics, statistics, economics, business
    - Can substitute three business-school electives
  - Capstone, either "Systems Engineering Project Course," a Project/Report course, or a thesis
- Master of Science in Industrial and Systems Engineering/*Diplôme de Formation Specialisée in Génie des Systèmes Industriels*[17]
  - Six core courses, which are focused on design, operations research, engineering, and facilities planning/materials handling
  - Two-course specialty track
    - Tracks available: manufacturing/operations research, management, ergonomics
      - Courses in manufacturing/operations research focus on manufacturing costs/production economies, operations research, modeling
      - Courses in management cover manufacturing management theory/practice and engineering/technology management
      - Courses in ergonomics focus on design, systems engineering/integration, macroergonomics, and human factors engineering
  - One elective in any of the three tracks listed above
  - Year-long thesis
- Doctor of Philosophy in Industrial and Systems Engineering
  - Same concentration options as above, with additional requirements:
    - Core coursework in the human factors engineering and ergonomics option primarily design-based

[17] This is a recently started international dual degree program with the Ecole des Mines de Nantes, France

- Additional requirements: one engineering management course, one operations research course, and one statistics course
- One elective focused on either design and engineering for the disabled and the elderly, rehabilitation, or health and safety

▪ Manufacturing Systems Engineering option:
- General and technical electives drawn from operations research, statistics, computer-integrated manufacturing, robotics and automation, and production systems

▪ Operations Research concentration:
- Coursework in methodology, design, production planning, and mathematics and statistics.[18]

o Additional distributional specifications *beyond* the master's curriculum

B. DOMAIN-CENTRIC PROGRAMS THAT INCLUDE SYSTEMS IN THE MAJOR

Domain-centric programs are defined as "basic or advanced level programs leading to a bachelors, masters, or doctoral degree with the major designated as X and Systems Engineering, Systems and X Engineering, etc.," according to Fabrycky.[19]

1. Auburn University

Location: Auburn, Alabama

Degrees Offered: Master of Science in Industrial and Systems Engineering; Master of Science; Master of Business Administration/Master of Science in Industrial and Systems Engineering; Doctor of Philosophy [20]

Degree Requirements:

- Master of Science in Industrial and Systems Engineering[21]
  - Six-course core curriculum focusing on facility design/operation, production and inventory control systems, ergonomics, engineering statistics, and linear/integer programming
  - Remaining four courses are concentrated in a student's area of specialization, which may be engineering economics, ergonomics and safety, operations research and statistics, or production and manufacturing

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18 "Methodology" courses are mostly focused on programming (e.g. Linear Programming).

19 Fabrycky, "Systems Engineering Academic Program Data Bases."

20 Students enrolled in the joint master's program start work on both degrees their first (autumn) semester and complete them in the spring term of their second year. During the summer, they engage in either an industrial internship or an unspecified "international experience."

21 Program aimed at working/traveling professionals and members of the armed forces, as thesis and residency not required.

- Master of Science
  - Same core curriculum and electives as above
  - Two-semester thesis
  - Residency of at least one semester
- Doctor of Philosophy
  - Minimum of two semesters' residency
  - Course requirements vary depending on the student's academic background, but a typical program of study consists of the aforementioned core, plus about six electives

Other Information:

- Many classes offered on video

2. California State University, Fullerton

Location: Fullerton, California

Degree Offered: Master of Science in Electrical Engineering with an option in Systems Engineering.

Degree Requirements:

- Minimum of 10 courses
- Electrical Engineering core:
  - "Computer Methods in Numerical Analysis"
  - "Advisor-approved math-oriented course"
  - Five systems engineering courses that emphasize linear theory, random-sequence analysis, optimization in systems engineering, and operations analysis in systems engineering
- Approximately electives in the areas of information systems, control theory, computer systems, civil and mechanical engineering applications of systems engineering, and optics and systems engineering.
- Thesis or project

3. Case Western Reserve University

Location: Cleveland, Ohio

Degrees Offered: Master of Science in Systems and Control Engineering; Doctor of Philosophy in Systems and Control Engineering

Degree Requirements:

- Master of Science in Systems and Control Engineering
  - No specific core curriculum outlined; individualized plans of study
    - Thesis track:

        - Six courses
        - Thesis
      - Non-thesis track:
        - Seven classes
        - Three-to-six-credit hour Special Project, the results of which must be presented to faculty in written and oral format
    - Fields of specialization available are control theory; optimization/decision theory; control of industrial/manufacturing systems; biomedical control systems design and analysis; energy systems; and global/environmental systems and control
- Doctor of Philosophy in Systems and Control Engineering
  - No specific core curriculum specified; individualized plans of study
    - Coursework corresponds to the fields of control theory/automation engineering, systems analysis and decisions theory, and manufacturing/industrial systems engineering
  - Six courses in the dissertation subject area
  - Four classes outside dissertation (half of which must be from outside the department)
  - Two classes in math or science

4. Colorado State University–Pueblo

Location: Pueblo, Colorado

Degree Offered: Master of Science in Industrial and Systems Engineering

Degree Requirements:

- Five core classes, drawn from ergonomics, scheduling/sequencing, simulation, project planning and control, operations planning and control, engineering economics, operations research, and facility planning and design
- Graduate seminar in Industrial and Systems Engineering
- Two to three elective courses in one of the following tracks: information systems; industrial engineering; engineering management; individualized track
- Optional thesis
  - Thesis option: two electives
  - Non-thesis option: three electives

5. Cornell University

Location: Ithaca, New York

Degree Offered: Master of Engineering with a Systems Engineering major

Degree Requirements:

- Minimum of 10 courses total
- Core curriculum:
  - Two-course core sequence in applied systems engineering[22]
  - One course in project management
  - Systems engineering project
- Systems Engineering Seminar, which consists of weekly lectures on topics relating to Systems Engineering, primarily by outside speakers
- Electives are chosen from the fields of systems simulation and modeling; Systems Applications; and Systems Management
  - At least one course must be from each of the systems simulation/analysis and systems management fields
  - Electives in which systems architecture is a topic: "Software Engineering," "Language Technologies," "Foundations of Artificial Intelligence"
    - Classes in systems simulation and modeling focus on simulation, feedback and control, risk analysis, operations research, and decision-making
    - Courses in systems application look at design and operation of specific systems, such as software and manufacturing
    - Systems management courses emphasize technical and human management

6. Georgia Institute of Technology (Georgia Tech)

Location: Atlanta, Georgia

Degrees Offered: Master of Science in Industrial Engineering; Master of Science in Human-Integrated Systems; Doctor of Philosophy with options in Manufacturing and Logistics and Human-Integrated Systems

Degree Requirements:

- Master of Science in Industrial Engineering
  - Coursework taken in one of two tracks: Manufacturing and Logistics; and Human-Integrated Systems

[22] "Applied Systems Engineering I" covers requirements analysis, decision-making, technical processes, tools, planning, and the life-cycle concept. "Applied Systems Engineering II" covers graphical systems engineering modeling, simulation methods, statistics, operations research (nonlinear and discrete optimization), and applications of decision-making.

- Manufacturing and Logistics track
  - Six-course core focusing on manufacturing systems, warehousing systems, transportation/supply chain systems, operations research, operations research, modeling, simulation, and engineering economics
  - Two area electives, which can come from either the Industrial and Systems Engineering department, or the Computing, Business, and Mathematics departments
  - Two non-departmental electives
- Human-Integrated Systems track
  - Six-course core divided between classes in human-machine systems (focusing on modeling, simulation, design, and decisionmaking) and those in operations research, simulation, and engineering economics
  - Four area electives, chosen from among cognitive engineering, modeling/simulation, realtime systems, and measurement[23]

- Master of Science in Human-Integrated Systems
  - Core curriculum: three courses in design of human-integrated systems, modeling, and decision-making
  - Two area electives, drawn from cognitive engineering, simulation, and measurement.
  - One class on statistical modeling and experimental design
  - Thesis
- Doctor of Philosophy, Option in Manufacturing and Logistics
  - Core curriculum: five courses distributed among optimization, stochastics, statistics, manufacturing systems, and transportation systems.
  - Six additional classes focusing on applied statistics, simulation, and special topics in manufacturing and logistics
- Doctor of Philosophy, Option in Human-Integrated Systems
  - Four core courses, the foci of which are the same as those for the Master of Science in Human-Integrated Systems
  - Two area electives, the foci of which are the same as those for the Master of Science in Human-Integrated Systems
  - Four methodology courses centered on optimization, advanced simulation, probability modeling, and statistical modeling/experimental design
  - Six additional graduate courses through the department in the areas of psychology, computing, graphics/visualization/usability, cognitive science, and/or another type of engineering

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[23] Can substitute courses from the School of Industrial and Systems Engineering; the Graphics, Visualization, and Usability Center; and/or the Departments of Computing, Psychology, Cognitive Science

7. Louisiana Tech University

Location: Ruston, Louisiana

Degrees Offered: Master of Science in Manufacturing Systems Engineering; Master of Science in Industrial Engineering; Doctor of Engineering in Industrial Engineering

Degree Requirements:

- Master of Science in Manufacturing Systems Engineering
  - Three-course core curriculum is drawn from the fields of electrical engineering, engineering, industrial engineering, and mechanical engineering.
  - Three "concentration courses" from any of the disciplines above
  - Two "broadening courses" (either non-engineering or cross-listed with engineering)
  - Two electives
  - Two-semester thesis or one-semester practicum
- Master of Science in Industrial Engineering
  - Eight to 12 courses total
  - Six core courses, which focus on facilities planning, quality engineering, and material management
  - Approximately two electives, drawn from courses on facilities planning, quality engineering, material management, human factors, facilities planning, and operations/facilities design
  - Areas of specialization available are operations research, manufacturing systems, statistics/quality control, robotics/artificial intelligence/expert systems, and human factors
  - Two-semester thesis or one-semester practicum
- Doctor of Engineering in Industrial Engineering
  - 14 mechanical engineering specialty courses
  - Six classes in the interdisciplinary engineering core, drawn from design, mechanics, aerothermodynamics, and cryogenics
  - Four courses in economics, management, or finance
  - Two classes in advanced mathematics
  - Six courses of research and dissertation

8. Massachusetts Institute of Technology

Location: Cambridge, Massachusetts

Degree Offered: Master of Science in Systems Design and Management

Degree Requirements:

- Three core courses, focusing on systems architecture, systems engineering, and systems/project management
- Six foundation courses, emphasizing risk-benefit analysis, financial accounting, marketing management, operations management, organizational processes, and systems optimization
- Four electives:
  - One management elective
  - One engineering elective
    - Two electives drawn from Product Development or Systems Design tracks
- Business trip:
  - 7- to 10-day international trip, for on-campus students
  - A few to campus, for distance-learning students
- January program
  - One-month-long, in-residence session for both distance-learning and on-campus students
- Thesis

Other Information:

- Distance-learning option available for company-sponsored students[24]
  - One full term in residence required
- On-campus option for those who are independent (i.e., not company-sponsored).

9. New Jersey Institute of Technology

Location: Newark, New Jersey

Degree Offered: Master of Science in Manufacturing Systems Engineering

Degree Requirements:

[24] There are 34 companies partnering with this program and sponsoring students; they include Intel, NASA, Hewlett-Packard, Dell, Compaq, Alstom, Motorola, Qualcomm, Raytheon, Northrop Grumman, Sun Microsystems, Boeing, General Motors, Ford, and Honeywell.

- Four core courses, emphasizing manufacturing systems, flexible and computer-integrated manufacturing, management of manufacturing systems, and design for manufacturability
- Six classes in an area of specialization
  - Areas of specialization: systems automation, systems analysis and design, computer control of manufacturing systems, management, and design for manufacturability
- Each semester: Manufacturing Engineer Seminar, if receiving a departmental or research award
- Thesis, project, or independent study

Other Information:

- Curriculum is computer and multimedia-intensive curriculum and emphasizes computer-aided design and manufacturing, systems control, robotics, and "efficient production in technologically intensive manufacturing industries"

10. North Carolina Agricultural and Technical State University

Location: Greensboro, North Carolina

Degrees Offered: Master of Science in Industrial and Systems Engineering; Doctor of Philosophy in Industrial and Systems Engineering.

Degree Requirements:

- Master of Science in Industrial and Systems Engineering
  - Four general core courses, focusing on production and control, information systems, ergonomics principles, and experiment design
  - Three specialized core courses
    - Specializations available are human-machine systems engineering; management systems engineering; production systems engineering; and operations research and systems analysis
      - Human-machine systems engineering core covers biomechanics, ergonomics, systems engineering modeling, human-machine systems, human-computer interface, engineering statistics, and engineering tools
      - Management systems engineering core examines engineering management, quality engineering, technology management, engineering economics, and supply-chain systems engineering
      - Production systems engineering core emphasizes simulation, robotics, computer-integrated manufacturing, and systems design
      - Operations research and system analysis core focuses on systems simulation, linear and nonlinear programming, optimization, and stochastic processes/queuing theory

- Up to three electives
- Two semesters of a noncredit seminar
- Optional thesis
  - Thesis option: 8 classes plus thesis
  - Non-thesis option:10 classes plus project

- Doctor of Philosophy in Industrial and Systems Engineering
  - 19 courses total
  - Two semesters of a noncredit seminar
  - One statistics course
  - One credit of teaching or research
  - Eight Industrial Engineering courses
  - Four electives
  - Classes in their area of specialization (limited to human-machine systems engineering, management systems engineering, and production systems engineering).
  - Qualifying and Preliminary Examinations, which count towards the degree requirements.

11. Northeastern University

Location: Boston, Massachusetts

Degree Offered: Master of Science in Computer Systems Engineering; Doctor of Philosophy in Computer Systems Engineering

Degree Requirements:

- Master of Science in Computer Systems Engineering
  - 12 courses total
  - Five core courses in one of two specialty options: computer-aided design/computer-aided manufacturing; engineering software design
    - Computer-aided design/computer-aided manufacturing core focuses on object-oriented design, computer-aide design/manufacturing, manufacturing methods/techniques, and engineering project management
    - Engineering software design core emphasizes object-oriented design, software development (component and enterprise), and software engineering
  - Two to three electives, selected from among courses on operations research, processes, design, human-computer interaction, robotics, engineering project management, systems software engineering, probability and statistics, simulation, expert systems/neural networks, object-oriented design, dynamics/mechanical vibrations, fracture mechanics/failure analysis, database management systems

- Thesis or project
- Doctor of Philosophy in Computer Systems Engineering
  - Specific course requirement not available; program of study determined by candidate and dissertation advisor

12. Ohio University

Location: Athens, Ohio

Degree Offered: Master of Science in Industrial and Manufacturing Systems Engineering

Degree Requirements:

- Thesis option:
  - Four core courses and at least eight electives (total 12)
  - One for-credit seminar in Industrial and Systems Engineering, taken during first three quarters of study
  - Year-long thesis (counts towards credit requirements)
- Non-thesis option:
  - Four core courses and at least 11 electives (total 15)
  - Project (counts towards credit requirements)
  - Seminar as above
- Coursework is taken in an area of specialization:
  - Manufacturing Information Systems, Manufacturing Systems, or Quality Systems
  - 4 core courses within each:
    - Manufacturing Information System core focuses on digital computer systems, information-systems engineering, and computer-integrated manufacturing
    - Manufacturing Systems core focuses on focuses on systems simulation, manufacturing systems engineering, and computer-integrated manufacturing
    - Quality Systems core emphasizes statistics and quality systems
  - Electives within:
    - Manufacturing Information System electives drawn from robotics, quality control, manufacturing systems engineering, systems simulation and design, neural networks, computer-aided design/manufacturing, and human-machine systems engineering
    - Manufacturing Systems electives include those on data modeling, quality control, non-linear processing, and various aspects of systems engineering and design

- Quality Systems electives are very analytically oriented and are centered around statistics, Bayesian analysis, manufacturing management, systems analysis, and cost engineering
-

13. Ohio State University

Location: Columbus, Ohio

Degrees Offered: Master of Science and a Doctor of Philosophy in Industrial and Systems Engineering

Degree Requirements:

- Master of Science in Industrial and Systems Engineering
  - Minimum of three courses in an area of specialization
    - Available areas: Human Factors, Manufacturing Process Engineering, and Operations Research
  - At least three classes in other areas of systems engineering
  - Unspecified number of electives
  - Thesis optional, except for human factors majors
    - Thesis option: 11 courses, plus two semesters of thesis
    - Non-thesis option: 11 courses, plus additional electives
- Doctor of Philosophy in industrial and systems engineering
  - At least seven classes in the major field
  - Three courses in each of two minor fields (one departmental and one nondepartmental)

14. Rensselaer Polytechnic Institute

Location: Troy, New York

Degrees Offered: Master of Science in Manufacturing and Systems Engineering; Master of Engineering in Manufacturing and Systems Engineering; Master of Engineering in Computer and Systems Engineering; Master of Science in Computer and Systems Engineering; Doctor of Engineering; Doctor of Philosophy in Computer and Systems Engineering[25]

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[25] Master of Engineering degrees are professional degrees and do not require a thesis or a project. Master of Science degrees are research-oriented, and, hence, require a thesis or a project. The Doctor of Engineering is characterized by a thesis that "proposes an engineering problem of substance and develops a solution to it in a creative and distinguished manner." ("Electrical, Computer, and Systems Engineering Deparment," Rensselaer Polytechnic Institute website, http://www.ecse.rpi.edu). Despite being offered at Rensselaer, it is rarely pursued.

Degree Requirements:

- Master of Science in Manufacturing and Systems Engineering; Master of Engineering in Manufacturing and Systems Engineering
  - Five core courses focusing on strategic management of technological innovation; concurrent engineering; simulation and modeling; management information systems; and quality control
  - Three classes in an area of concentration
    - Available areas: Manufacturing Systems Modeling, Manufacturing Systems Quality, Manufacturing Process and Technology, Information Systems, Systems Engineering
    - Coursework in all these fields focus on process, statistics, analysis, design, management, and systems
  - Up to two electives
  - Thesis or project (Master of Science only)
- Master of Engineering in Computer and Systems Engineering
  - Minimum 10 courses total
  - Three-course technical concentration
    - Concentrations available: advanced circuit design; computer communication networks; computer graphics and visualization; digital image and signal processing; electronics manufacturing; electric power; microelectronics manufacturing; VLSI design; robotics, automation and manufacturing
  - Two-course sequence (non-technical) chosen from outside the department
  - A minimum of six to seven graduate-level courses, counted as departmental or technically related electives
    - No more than two classes should be technically related courses; drawn from Electric Power, Computer Science, Materials Engineering, Physics Departments
  - Optional Professional Project
- Master of Science in Computer and Systems Engineering
  - Minimum 10 courses total
  - Minimum of eight graduate-level courses, most of which are counted as departmental or technically related electives
    - Technically related courses drawn from same departments as for Master of Engineering
  - Year-long thesis, counted in credit/course totals
- Doctor of Philosophy in Computer and Systems Engineering
  - 20 courses beyond the master's, or if entering program without a master's, 30 courses beyond the bachelor's
  - Specific course requirements not indicated; program of study to be determined by candidate, in conjunction with advisor

Other Information:

- Some courses are offered through distance learning

15. Rochester Institute of Technology

Location: Rochester, New York

Degrees Offered: Master of Science in Product Development; Master of Engineering in Systems Engineering; and Master of Science in Engineering in Systems Engineering

Degree Requirements:

- Master of Science in Product Development[26]
  - 13 courses total
    - 10 core courses, focusing on product development, systems engineering (two classes), systems and project management, organizational behavior, operations and manufacturing systems, systems optimization, financial accounting systems, risk-benefit analysis, and marketing concepts
      - Note: the two systems engineering core courses, "Engineering of Systems I/II," focus on systems architecture
    - Three electives, drawn from quality engineering, various aspects of business/management (technology, research and innovation, design, and product), systems dynamics, and product design
  - Capstone Research Project
- Master of Engineering in Systems Engineering
  - Nine core courses, focusing on operations research (linear programming), data structures, statistical analysis, systems integration, computer-integrated manufacturing, mathematical programming, experiment design, systems simulation, quality control systems, reliability
  - Three electives
- Master of Science in Engineering in Systems Engineering
  - Same as above, plus two electives and thesis

Other Information:

- Both master's programs have substantial coursework in systems engineering

[26] Program geared towards working professionals.

16. Rutgers University

Location: New Brunswick, New Jersey

Degrees Offered: Master of Science in Industrial and Systems Engineering; Doctor of Philosophy in Industrial and Systems Engineering

Degree Requirements:

- Master of Science in Industrial and Systems Engineering
  - Seven to nine courses in one of four tracks: Industrial Engineering, Quality and Reliability Engineering, Manufacturing Systems Engineering, Information Technology
    - Industrial Engineering track
      - Four-course core: "Stochastic Models in Industrial Engineering," "Deterministic Models in Industrial Engineering," "Production Analysis," and "Simulation of Production Systems"
      - Advisor-approved electives
    - Manufacturing Systems Engineering track
      - Seven-course core curriculum focusing on systems simulation, production analysis, computer-integrated manufacturing, robotics, and process and design
      - Two unspecified "additional courses"
      - One technical elective drawn from facilities planning/design, systems analysis, laser-based micromanufacturing, and experiment design
      - Project
    - Quality and Reliability Engineering track
      - One course each in life data analysis, experiment design, and quality management
      - Two-course sequence in systems reliability engineering and statistical quality control
      - Limited number of electives
    - Information Technology track
      - Nine core courses, drawn from Industrial and Systems Engineering, Electrical and Computer Engineering, Computer Science and the Business School[27]
  - Three electives

[27] Courses from Industrial and Systems Engineering focus on computer-integrated manufacturing, systems simulation, computational methods, and manufacturing information systems; the one from Electrical and Computer Engineering examines communication networks; and the one from Computer Science focuses on computer structures and algorithms. The business school course is on Internet technology.

- Three semesters of Industrial Engineering Seminar (non-credit), in which guest speakers from industry and academia present their research
- Optional thesis
  - Thesis option: eight courses, plus thesis
  - Non-thesis option: 10 courses, plus comprehensive exam or project

- Doctor of Philosophy in Industrial and Systems Engineering
  - Five-course core focusing on deterministic and stochastic modeling, production analysis, systems reliability engineering, experimental design, and mathematics for industrial engineering[28]

17. San José State University

Location: San José, California

Degree Offered: Master of Science in Industrial and Systems Engineering

Degree Requirements:

- 10 courses total
  - Five-course core focusing on engineering economics, human factors and ergonomics, operations research, and quality assurance and reliability
  - Four courses in one of three areas of specialization: Production and Quality Assurance; Systems and Information Modeling; and Human Factors
    - Classes in the Production and Quality Assurance track focus on production and control, operations research, and supply chain management
    - Systems and Information Modeling courses examine, among other things, information engineering, systems simulation, operations planning and control
    - Courses in the Human Factors track emphasize human-computer interaction, experiment design, and experimental ergonomics
- One elective from one of the areas mentioned above
- Thesis or project (counts as one of the 10 courses)

18. Texas Tech University

Location: Lubbock, Texas

Degrees Offered: Master of Science in Manufacturing Systems Engineering; Master of Science in Systems and Engineering Management.

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[28] The remaining coursework is not specified; presumably, it is drawn from the areas of specialization outlined for the master's and from relevant electives.

Degree Requirements:

- Master of Science in Manufacturing Systems Engineering[29]
  - Core courses focus on "theory and practice in design, control, and managing manufacturing systems"
  - One-semester internship
- Master of Science in Systems and Engineering Management
  - Seven-course core covering organization principles, systems theory, decision theory, engineering management, production and performance improvement, total quality systems, and simulation models
  - Up to four electives, focusing on safety engineering, human factors engineering, industrial cost analysis, and inventory systems
  - Thesis option: eight courses plus year-long thesis
  - Non-thesis option: twelve courses
  - Courses offered on-campus and through distance educatio

19. University of Alabama, Huntsville

Location: Huntsville, Alabama

Degrees Offered: Master of Science in Engineering (Systems Engineering Option); Doctor of Philosophy in Industrial and Systems Engineering

Degree Requirements:

- Master of Science in Engineering (Systems Engineering Option)
  - Four core courses, three of which focus on systems engineering, economic analysis, and integrated product and process design
    - Remaining core course chosen from among project management, technology implementation, value and decision theory classes
  - Two minor fields
    - Two courses in each
    - Fields available: systems modeling, systems engineering, manufacturing systems, systems simulation, reliability engineering, technology management, engineering management, and operations research
      - Systems modeling courses emphasize simulation and modeling
      - Systems engineering courses focus on "methods of needs identification," life-cycle concept, logistics planning and control, forecasting, quality control, and design and modeling

[29] Little information about this program, beyond the internship requirement and a general overview of the core curriculum, is available.

        - Engineering management courses focus on management and human relations
        - Manufacturing systems engineering offerings focus on design, analysis, and implementation of manufacturing and productive systems and are drawn from the areas of programming, robotics, automated systems, computer integrated manufacturing, systems simulation, quality control, engineering economics, ergonomics, and systems engineering
        - Operations research coursework is drawn from optimization, stochastic systems analysis, modeling, queuing, Markov processes, linear programming, and operations research applications
    - Thesis option:
        - Thesis (1 to 1½ semesters), no electives
    - Non-thesis option:
        - Three electives, project
- Doctor of Philosophy in Industrial and Systems Engineering
    - Six core courses, focusing on systems engineering, human factors/systems design, integrated product and process design, engineering economics, and system modeling
    - Two minor fields
        - Areas available are same as for master's, described above
        - Five courses in the first minor field
        - Four courses in the second minor
        - One of the minors (usually the second) should be in mathematics or engineering mathematics/statistics
    - Five supporting electives, chosen to support the student's professional and academic goals
    - Two courses in language or ancillary skills, can also be drawn from minor areas

Other Information:

- Some components of the master's and doctoral programs are offered through distance learning

20. University of Central Florida

Location: Orlando, Florida

Degrees Offered: Master of Science in Industrial Engineering; Master of Science; Doctor of Philosophy in Industrial Engineering

Degree Requirements:

- Master of Science in Industrial Engineering
  - Breadth option:
    - Six core courses which focus on management information systems, project engineering, engineering analysis, engineering statistics, reliability engineering, and experimental design
    - Six electives and a comprehensive examination, or two electives plus a thesis
  - Depth option:
    - Study concentrated in one of the seven tracks — interactive simulation and training; manufacturing engineering; simulations modeling and analysis; quality engineering; operations research; engineering management; human factors and ergonomics
      - Courses in all seven cover manufacturing processes and systems, systems design and engineering, stochastic processes, engineering statistics, linear programming, experiment design, and simulation
- Master of Science
  - Study focused in one of seven tracks described above
  - Optional thesis
- Master of Science in Systems Engineering and Management[30]
  - Ten courses, focusing on project engineering, manufacturing information systems, decision analysis/risk assessment, quality management, simulation, systems engineering, operations engineering, engineering economy, environment of technology organizations, and engineering management
  - Space Industry Seminar Series
    - Seminars discuss human safety engineering, risk assessment, reliability analysis, and leadership
- Doctor of Philosophy in Industrial Engineering
  - Seven core courses, which emphasize project engineering, production and inventory control, economic analysis, engineering statistics, operations research, discrete systems simulation, and experiment design
  - Three to four classes in their area of specialization, which is drawn from the seven fields mentioned above
  - Eight to 10 electives, two of which must come from an area outside their specialization

[30] Program is 21 months long, designed for working professionals.

21. University of Connecticut

Location: Storrs, Connecticut

Degree Offered: Master of Science in Electrical Engineering with a concentration in Communication and Control Systems

Degree Requirements:

- Thesis option:
  - Five core courses, focusing on systems theory, operations research (applied probability and stochastic processes), digital signal processing, communications theory, and estimation and filtering
  - One elective
  - Thesis (three semesters)
- Non-thesis option:
  - Core curriculum, as above
  - One independent study
  - Two electives, drawn from the Communication and Control Systems area
  - One seminar

22. University of Houston[31]

Location: Houston, Texas

Degrees Offered: Master of Science in Computer and Systems Engineering; Doctor of Philosophy in Computer and Systems Engineering

Degree Requirements:

- Master of Science in Computer and Systems Engineering
  - Unspecified number of core courses focusing on mathematical concepts, computer and information engineering, computer systems design, computer systems, and systems theory
  - Unspecified number of electives, topics unknown
  - Optional master's thesis
    - Thesis option: 10 courses total, including paper
    - Non-thesis option, 12 courses
- Doctor of Philosophy in Computer and Systems Engineering
  - Curriculum not specified

[31] Not to be confused with the University of Houston, Clear Lake, which offers a Master of Science in Systems Engineering and is located near Clear Lake in Houston, between Houston and Galveston.

23. University of Michigan, Ann Arbor

Location: Ann Arbor, Michigan

Degrees Offered: Master of Science in Electrical Engineering: Systems; Doctor of Philosophy in Electrical Engineering: Systems

Degree Requirements:

- Master of Science in Electrical Engineering: Systems
  - 10 courses total
    - Three in a major field
      - Fields available: Communications; Control; Signal Processing
        - Communications courses include those on operations research, systems theory, digital communication signals and systems, and processes
        - Control courses center on operations research, linear systems theory, systems design, methods in systems theory, and discrete event systems
        - Signal Processing courses cover digital systems processing, systems theory methods, and stochastics
    - Two in minor field
      - Fields available: Communications; Control Systems; Signal Processing; Biosystems; Circuits and Microsystems; Computers; Electromagnetics; Manufacturing; Optics; Solid State
        - Computers courses look at systems design and processes
        - Manufacturing courses cover decision analysis; production and inventory control; systems design; reliability engineering; engineering statistics; and engineering design optimization
  - "Cognate" courses (electives), which include those in robotics, systems theory, systems science, systems design, stochastic processes, and specific systems
  - Optional thesis
- Doctor of Philosophy in Electrical Engineering: Systems
  - 12 courses total
    - Major/minor field distribution options (areas available same as for Master of Science):
      - Three courses in major field, one course in minor
      - Four courses in major field, none in minor
  - Four graduate electives
  - Technical electives, amount not specified
  - Unspecified number of cognate courses

24. University of Michigan, Dearborn

Location: Dearborn, Michigan

Degrees Offered: Master of Science in Engineering in Industrial and Systems Engineering; Master of Science in Engineering in Manufacturing Systems Engineering; Master of Science in Information Systems Technology; Master of Science in Engineering in Industrial and Systems Engineering/Master of Business Administration

Degree Requirements:

- Master of Science in Engineering in Industrial and Systems Engineering
  - Three core courses: "Design and Analysis of Experiments," "Manufacturing Information Systems," and "Product Management"
  - Four courses in an area of concentration (three if writing a thesis)
    - Areas of concentration: Industrial and Systems Engineering; Manufacturing and Concurrent Engineering; Information Systems
      - Industrial and Systems Engineering courses emphasize human performance and operations research
      - Manufacturing courses focus on manufacturing and quality systems design and advanced manufacturing and automation.
      - Information Systems courses center on information systems management and manufacturing information systems
  - Two nondepartmental electives, one of which must deal with the structure of organizations
- Master of Science in Engineering in Industrial and Systems Engineering/Master of Business Administration
  - Four core Industrial and Systems Engineering courses, which focus on optimization, multivariate statistics, production management, and experiment design and analysis
  - Nine management courses
  - Two managerial-applications classes[32]
  - Four courses from the concentration areas mentioned above
  - Two electives, chosen from management, industrial and systems engineering, electrical and computer engineering, or mechanical engineering
    - One course should be from management
    - Can substitute a thesis for the electives requirement

[32] One of the managerial-applications courses must be drawn from cost, global, or financial management; the other, from management skills, human-resources management, information management, or marketing management.

- Master of business administration capstone project

- Master of Science in Engineering in Manufacturing Systems Engineering
  - Six core courses, focusing on design, engineering economics, manufacturing systems, product manufacturing, and total quality management
  - Four specialty-track courses
    - Areas available: Manufacturing Systems, Manufacturing Processes, Manufacturing Management
  - Two electives
    - Electives available include courses on such subjects as "fuzzy systems," computer graphics, digital signal processing, and materials engineering
  - Optional thesis, substituted for elective work
- Master of Science in Information Systems Technology
  - Five-course core emphasizing computer networks, decision-making and organizational information systems, and object-oriented systems design
  - Three courses in one of the two areas of specialization: Management Information Systems and Service Information Systems
    - Management Information Systems courses are based on systems and management
    - Service Information Systems classes focus on finance, management, marketing, and organizational theory, as well as their applications
    - Two electives
      - Electives available cover such topics as network theory, modeling of computer-based systems, programming, and processing

25. University of Pittsburgh

Location: Pittsburgh, Pennsylvania

Degree Offered: Master of Science in Industrial Engineering; Doctor of Philosophy in Industrial Engineering

Degree Requirements:

- Thesis option:
  - Eight courses total, plus thesis
    - Four-course core curriculum of "Probability and Statistics for Engineers," "Introduction to Manufacturing Systems," "Operations Research," and either "Engineering Management," "Database Design," or "Statistics/Data Analysis"

        - Electives in an area of concentration
            - Areas available: Information Systems Engineering; Product Realization and Manufacturing Systems; Operations Research; Engineering Management
                - Information Systems coursework draws on databases, networks, e-commerce, production/inventory control, cost management, total quality manufacturing, and production scheduling
                - Product Realization and Manufacturing Systems classes emphasize reverse engineering, rapid prototyping/manufacturing, and engineering-relevant aspects of business and management
                - Operations Research courses focus on optimization, simulation, nonlinear programming, probability and statistics, integer/dynamic programming, experimental design, and reliability
                - Engineering Management coursework is drawn from the above three fields and from decision analysis and modeling
- Non-thesis option:
    - 10 courses total
    - Core as above
    - Area of concentration/electives as above
        - Two non-departmental graduate courses may be substituted for two of the departmental electives
- Doctor of Philosophy in Industrial Engineering
    - Six core courses, focusing on operations research, engineering management, probability and statistics (two courses), manufacturing systems
    - One course each on linear optimization, stochastic processes, digital signals simulation
    - Nine electives, two of which should be nondepartmental
    - Journal Seminar, taken in second year of study
    - Teaching Practicum

26. University of St. Thomas

Location: St. Paul, Minnesota

Degree Offered: Master of Manufacturing Systems Engineering

Degree Requirements:

- 15 courses total
  - Nine core courses, focusing on manufacturing systems design, performance measurement, operations research, program/project management, materials engineering, statistics, and experimental design
  - One course from the Process, Assembly, and Product Engineering field
    - Courses in this area include those on computer-aided design, computer-aided manufacturing, and systems design and analysis
  - Five electives, focusing on design and manufacturing, systems design and engineering, systems simulation, risk and quality management, engineering economics, and processes
    - In lieu of electives, may choose four-course concentration in one of the following fields: Quality; Product Development; Software; Engineering Management; Technology Management; Medical Device
  - Capstone course
  - Project or thesis

27. University of South Florida

Location: Sarasota/Manatee, Florida

Degrees Offered: Master of Science in Engineering Management, Master of Science in Industrial Engineering; Master of Science in Engineering with a Manufacturing Systems Option

Degree Requirements:

- Master of Science in Engineering Management
  - Four-course core covering principles of engineering management
  - One "Quantitative Area" course drawn from statistics, statistical modeling, or operations research
  - One "Job Design" course drawn from human relations or productivity engineering
  - Five advisor-approved electives
  - Engineering management capstone
  - Comprehensive examination
- Master of Science in Industrial Engineering
  - Four-course core focusing on industrial statistics theory, manufacturing systems analysis, statistical design and modeling, and multivariate optimization
  - Four electives in an area of concentration
    - Areas available: Engineering Management, Manufacturing Systems, Quantitative Analysis
  - Thesis

- Master of Science in Engineering with Manufacturing Systems Option
  - Six-course core covering same topics as Master of Science in Industrial Engineering
  - Six electives from the specialties of robotics, automation, computer-aided design, computer-integrated manufacturing, control systems, software systems, hardware systems, and production systems

28. Virginia Tech

Location: Blacksburg, Virginia

Degrees Offered: Master of Science in Management Systems Engineering; Master of Science in Manufacturing Systems Engineering; Doctor of Philosophy in Management Systems Engineering; Doctor of Philosophy in Manufacturing Systems Engineering

Degree Requirements:

- Master of Science in Management Systems Engineering
  - Seven core courses:
    - Four focusing on management systems theory/design/application; management of change, innovation and performance (two-course sequence); applied systems engineering, systems engineering process
    - One class in either operations research, manufacturing systems engineering, or human factors engineering
    - One non-credit seminar
  - Technical electives
    - Chosen in conjunction with advisor; may select courses in quality/reliability management; production/performance measures and improvement; modeling of performance measurement systems, among other subjects
      - Thesis option: two electives
      - Non thesis option: four electives, one of which should be from the Industrial and Systems Engineering department
- Doctor of Philosophy in Management Systems Engineering
  - Core curriculum same as for Master of Science in Management Systems Engineering
    - Unspecified amounts of technical electives and remaining coursework, to be chosen in conjunction with student's research field

- Master of Science in Manufacturing Systems Engineering
  - Nonthesis option:
    - Six core courses, focusing on industrial automation, manufacturing systems engineering, facilities planning/materials handling, optimization, simulation, and production planning/control
    - Five (or more) electives in one of three specialty tracks
      - Tracks available: Computer-Integrated Manufacturing; Robotics and Automation; Production Systems
  - Thesis option:
    - Four core courses, focusing on industrial automation, manufacturing systems engineering, facilities planning/materials handling, and production planning/control
    - Four electives, chosen either from specialty track (described above) or general manufacturing electives
    - Thesis
- Doctor of Philosophy in Manufacturing Systems Engineering
  - Four core courses, same topics as for thesis option, Master of Science in Manufacturing Systems Engineering
  - Four general manufacturing electives, covering topics such as optimization, simulation, statistics, experiment design, random processes, queuing/graph theory
  - Two electives from one of the three specialty tracks (Computer-Integrated Manufacturing; Robotics and Automation; Production Systems)

29. Washington University

Location: St. Louis, Missouri

Degrees Offered: Master of Science in Systems Science and Mathematics; Doctor of Science in Systems Science and Mathematics

Degree Requirements:

- Master of Science in Systems Science and Mathematics
  - Five core courses that focus on linear and nonlinear dynamic systems, operations research, and computational methods
  - Remaining coursework drawn from systems theory, decision and control theory, applied mathematics, operations research, and numerical analysis
  - Optional thesis
- Doctor of Science in Systems Science and Mathematics
  - Core same as above
  - Five additional courses on operations research and calculus

30. Wichita State University

Location: Wichita, Kansas

Degrees Offered: Master of Science in Industrial Engineering; Doctor of Philosophy in Industrial Engineering

Degree Requirements:

- Master of Science in Industrial Engineering
  - Five core courses, focusing on industrial ergonomics, operations research, production systems, statistical methods, and engineering research writing
  - Three major-area classes
  - Up to two technical electives
  - Three study options: thesis, directed project, "all-course"
    - Thesis option: Eight courses, plus year-long thesis
    - Directed project option: Minimum 10 classes, plus one-semester directed project
    - "All-course" option: Minimum 11 courses, plus written core competency examination
- Doctor of Philosophy in Industrial Engineering
  - Two-course core focusing on engineering statistics and engineering research writing
  - Seven courses in a major field
    - Fields available: manufacturing systems engineering; engineering systems; ergonomics/human factors
  - Three classes in a minor field
    - Fields available: manufacturing systems engineering; engineering systems; ergonomics/human factors, computer science, psychology, other engineering discipline
  - Technical electives, focusing on, *inter alia*, simulation, quality engineering, operations research, supply chain management, safety engineering, manufacturing processes and systems, and decision-making
  - Two classes in calculus-based mathematics and/or statistics

APPENDIX C
CERTIFICATE PROGRAMS IN SYSTEMS ENGINEERING

CONTENTS

CERTIFICATE PROGRAMS IN SYSTEMS ENGINEERING

This appendix covers certificate programs, which generally arise in conjunction with graduate programs to fulfill an industry or defense need. Certificate programs tend to include some amount of work experience. Many companies have developed their own education and training programs in cooperation with local universities.

A. AEROSPACE CORPORATION/AEROSPACE INSTITUTE

Location: Los Angeles and Washington, DC

Certificate Offered: Aerospace Systems Architecting and Engineering Certificate

Program Information:

- One-year program, 170 course-hours
- Designed to increase the "corporate reservoir" of aerospace personnel with systems architecting-engineering perspective and skills
- Aimed at Aerospace Corporation employees, though DOD military/civilian personnel (but not reservists or consultants) and some Federally Funded Research and Development Center employees (up to 20% of class capacity) may attend

Course Requirements:

- One core course, "Aerospace Roles in Space Systems Architecting, Acquisition, and Engineering"
- Unspecified number of classes in either Aerospace Systems Architecture Program or Space Systems Engineering Program
- Unspecified number of specialty courses (electives), drawn from systems engineering; architecting; computer systems; security systems; communications systems; customer systems; satellite systems; cost; engineering and science
- Internship (length and number not specified)

B. AIR FORCE INSTITUTE OF TECHNOLOGY

Location: Air Force bases worldwide

Certificate Offered: Graduate Certificate in Systems Engineering

Program Information:

- Courses offered on-campus and through distance learning

Requirements:

- Four core courses
  - "Introduction to Software Engineering"
  - "Systems Engineering Process and Requirements Driven Design"
  - "Systems Architecture"
  - "Systems Engineering Management"
- Capstone project
  - May substitute one of the following distribution courses: "Cost Management," "Project Risk Analysis," "Cost Analysis for System Design," "Engineering Economics," "Human Computer Interaction"
- Group project

C. CALIFORNIA INSTITUTE OF TECHNOLOGY

Location: Pasadena, California

Certificate Offered: Graduate Certificate in Systems Engineering

Program Information:

- Certificate offered through the University's Industrial Relations Center and can be a customized program depending on the needs of a specific company
  - Some customized certificate programs:
    - 40-hour Systems Engineering Certificate Program, 5 full days or 10 half-days of lectures and group exercises covering all aspects of systems engineering
    - 56-hour Systems Engineering Certificate Program, "Expanded topics and lectures with an in-depth threaded exercise, typically a full, one-day course per month for seven consecutive months"
- Thirteen different topics are covered in short courses, including: "Understanding Systems and Systems Engineering," "Creating a High-Performing Team for Systems Engineering," "Constructing Systems Engineering Requirements," "Performing a Functional Analysis," "Developing a Systems Architecture," "Performing System Design and Development," "Conducting Technical Reviews and Audits," "Using Configuration Management," "Verification and Validation Testing," "Managing Risk," "Managing System Cost and Schedule Estimation," "Producing the System," and "Systems Engineering Management and Planning"

D. INTERNATIONAL COUNCIL ON SYSTEMS ENGINEERING

Location: Seattle, Washington state

Certificates Offered: Certified Systems Engineering Professional; Systems Engineering Management Certification; Certified Systems Engineering Specialists; Systems Engineering Enterprise Processes Certification (all proposed)

Program Information:

- Certification program under development in 2003, possible formal start in early 2004
- Planned certification levels:
  - Systems Engineering Professional
    - Foundational level of knowledge, aimed at engineering graduates with several years discipline experience moving into positions with systems engineering responsibility
    - Certification achieved via written exam, Systems Engineering Foundations
      - Exam beta tested, 30 June 2003, and consists of 300 questions in 5 sections (General Systems Engineering Knowledge; Systems Engineering Management; Requirements and Architecture Definition; Systems Integration, Verification, and Validation; Engineering Process Management)
  - Systems Engineering Management
    - Certification level represented by the quality of professional experience, "job roles with increased responsibility and demand for leadership abilities," and systems engineering knowledge "demonstrably above" the Systems Engineering Professional certification
  - Systems Engineering Specialists
    - Envisioned as a set of specialty certificates in such subjects as requirements engineering, systems analysis, modeling and simulation, verification and validation, and reliability engineering
  - Systems Engineering Enterprise Processes
    - Certification level for those doing enterprise-level work

Admission Requirements:

- Certified Systems Engineering Professional (proposed)
  - 5 years of experience
  - Baccalaureate in technical field (can substitute professional experience if no degree held)
  - 5 additional years' professional experience, if holding a bachelor's, for a total of 10 years' experience

- If no bachelor's, 5 additional years professional experience, for a total of 15 years' experience
- 3 peer recommendations
- Application, fee, transcripts

E. JOHNS HOPKINS UNIVERSITY

Location: Baltimore, Maryland

Certificate Offered: Graduate Certificate in Systems Engineering

Program Information:

- Designed for those who may not have the opportunity to pursue the entire master's degree, or may wish to focus their studies on a specific subject area

Admissions Requirements:

- Same requirements as for master's

Course Requirements:

- Six courses, chosen in consultation with an advisor

F. MASSACHUSETTS INSTITUTE OF TECHNOLOGY/UNITED TECHNOLOGIES CORPORATION (UTC)

Location: Cambridge, Massachusetts; Hartford, Connecticut

Certificates Offered: Systems Engineering Certificate; Systems Engineering Certificate for Managers and Supervisors

Program Information:

- Systems Engineering Certificate
  - One course per semester is taken, over a 12-month period, via distance learning (videoconferencing)
- Systems Engineering Certificate for Managers and Supervisors
  - Aimed at managers and supervisors of systems engineering professionals
  - Program "includes opportunities to participate in live Web-based seminars, alumni learning events and distance courses"

Admission Requirements:

- Systems Engineering Certificate
  - Undergraduate degree in Engineering or a related field, with a GPA of 3.0 or better
  - Undergraduate and graduate transcripts
  - Completed application form

- Management nomination to program
- Systems Engineering Certificate for Managers and Supervisors
  - Not specified

Requirements:

- Systems Engineering Certificate
  - Two core courses, "Systems Architecture" and "Systems Engineering"
  - One elective, "Product Design and Development"
  - Ten days of workshops -- 5 at MIT, 5 in Hartford, Connecticut
    - Workshops cover such topics as "Systems Dynamics and Systems Thinking," "Managing Technology and Innovation," "Organizational Processes," and communicating in groups and teams
  - Year-long capstone on a topic "tied to UTC business interests" and presented to UTC at a workshop
- Systems Engineering Certificate for Managers and Supervisors
  - Six days of workshops, taken over a three-month period and held in three sessions of two 1-day workshops each
    - Workshops cover the following topics: "System Architecture," "System Behaviors," "Systems Engineering Methods," "Systems Dynamics and Systems Thinking,' "Managing Technology and Innovation," "Managing Changes in Work and Organizations"

G. NAVAL POSTGRADUATE SCHOOL

Location: Monterey, CA

Certificate Offered: Systems Engineering Certificate

Program Information:

- One-year program utilizing both distance-learning and classroom-based modes of instruction
- Prerequisite: completion of Systems Analysis certificate

Requirements:

- Four courses:
  - "Program Management"
  - "Systems Engineering and Architecture"
  - "Cost Analysis"
  - "Logistics Systems Engineering"
- Capstone Project, worked on during last three courses mentioned above

H. PORTLAND STATE UNIVERSITY

Location: Portland, Oregon

Certificate Offered: Graduate Certificate in Systems Engineering Fundamentals

Program Information:

- Not available

Admission Requirements:

- Degree in Engineering; minimum 3.0 GPA
- Official transcripts
- Letters of reference
- Letter of intent
- Application form

Course Requirements:

- Three core courses: "Systems Engineering Approach," "Operations Research in Engineering Management," "Hardware and Software Integration"
- One of three Systems Science Department modeling courses: "Business Process Modeling and Simulation," "Discrete Multivariate Modeling," "Manufacturing Systems Simulation"

I. RELIABILITY ANALYSIS CENTER/AMERICAN SOCIETY OF NAVAL ENGINEERS/ADVANCED AUTOMATION CORPORATION

Location: Various, nationwide

Certificate Offered: Integrated Systems Engineering for Product Support Management Professional Certificate

Program Information:

- Series of 3-day courses for program managers, product managers, operations managers, production engineers, product development staff, supply chain managers, logistics managers, and maintenance managers
- Courses cover design, development, improvement, and operation of products and systems throughout the life cycle

Courses:

- "Specialty Engineering for Product Support: Systems, Applications, and Integration"
  - Intensive overview of specialty engineering disciplines within systems engineering
  - Overview of concepts in systems engineering

- Focuses on reliability engineering; maintainability engineering; testability engineering; human factors engineering; training systems development; supportability analysis; manufacturing engineering; information technology; software engineering

- "Maintenance Engineering: Principles and Applications"
  - Overview of maintenance engineering for product/system life cycle
  - Focuses on maintenance design methods; maintenance predictions; analysis; testing and demonstration; operational systems engineering principles and applications
- "Systems Engineering: Principles and Implementation"
  - Overview of systems engineering and lifecycle applications
  - Focuses on systems engineering standards, models, technical management, analysis and evaluation, product realization, product control, configuration and data management, product support
  - Integrates manufacturing, logistics, environment, and human factors disciplines

J. RENSSELAER POLYTECHNIC INSTITUTE

Location: Troy, New York

Certificate Offered: Certificate in Manufacturing Systems Engineering

Program Information:

- Offered through Office of Professional and Distance Education
  - Program not available online
- Must complete all four courses with a grade of B or higher

Admission Requirements:

- Application form; undergraduate transcripts
- Minimum 3.0 undergraduate GPA
- Bachelor's degree in engineering, mathematics, physics, chemistry, or computer science
- Completion of prerequisite courses, if necessary

Course Requirements:

- Four courses
  - "Analysis of Manufacturing Processes," "Manufacturing Systems Integration," "Manufacturing Systems Management," "Competitive Advantage and Operations Strategy"

K. SOUTHERN METHODIST UNIVERSITY

Location: Dallas, Texas

Certificates Offered: Certificate in Systems Engineering Fundamentals; Certificate in Systems Analysis; Certificate in Systems Design and Development (focus certificate); Certificate in Specialty Systems Engineering (focus certificate)

Program Information:

- Certificate series is a subset of the Master of Science in Systems Engineering program described in Appendix B, Section A.13.
- Series is designed for the engineering professional seeking education to support focused career objectives
- Can receive two certificates upon completion of core Master of Science in Systems Engineering courses
- Can apply for a Master of Science in Systems Engineering at any point; courses taken for certificate can be applied to masters program

Admission Requirements:

- Undergraduate degree in engineering, mathematics, or related field, along with a GPA of at least 3.0 in undergraduate and graduate work. Minimum of two years college-level mathematics, including at least one year of calculus. Applicants who do not meet the requirements may be admitted conditionally and required to take "bridging" courses for undergraduate credit

Course Requirements:

- Core tier:
  - Certificate in Systems Engineering Fundamentals:
    - Three courses: "Systems Engineering Process," "Integrated Risk Management," "Systems Integration and Testing"

    plus
  - Certificate in Systems Analysis:
    - Two courses: "Systems Analysis Methods" and "Systems Analysis and Optimization"
- Focus tier: two additional courses
  - "Systems Design" and "Software Systems Engineering" for Certificate in Systems Design and Development
  - "Reliability Engineering" or "Systems Reliability Engineering" and "Logistics Systems Engineering" for Certificate in Specialty Systems Engineering

L. SOUTHERN POLYTECHNIC STATE UNIVERSITY

Location: Marietta, Georgia

Certificates Offered: Graduate Certificate in Systems Engineering; Advanced Graduate Certificate in Systems Engineering

Program Information:

- Graduate Certificate designed for professionals who may not be actively involved in performing systems engineering tasks, but have management responsibilities in the area
- Advanced Graduate Certificate builds on the Graduate Certificate and is intended for professionals who have specific work and performance responsibilities in systems engineering
- Completion of both certificates leads to Master of Science in Systems Engineering (described in Appendix B, Section A.14)

Admissions Requirements:

- Graduate Certificate in Systems Engineering
  - "An appropriate Bachelor's degree with a GPA of 3.0 or better" and an official undergraduate transcript
  - Test of English as a Foreign Language (for applicants who are not native speakers of English); minimum of 213 on the computer version and 550 on the paper version
- Advanced Graduate Certificate in Systems Engineering
  - The above requirements, plus minimum Graduate Record Examination scores of 350 Verbal, 600 Quantitative and an Analytical Writing score of 4.0 (out of 6.0)

Course Requirements:

- Graduate Certificate in Systems Engineering
  - Four courses
    - "Introduction to Systems Engineering"
    - "Managing the Technical Effort Associated with Systems Creation"
    - "Systems Analysis and Systems Design"
    - "System Architecture"
- Advanced Graduate Certificate in Systems Engineering
  - Graduate Certificate core courses as listed above
  - Two additional core courses: "Engineering Economic Analysis" and "Verification Program Development and Management"
  - Two electives, chosen from "Modeling and Simulation," "Advanced Configuration Management," "Process Assessment and Improvement," and "Software Project Management"

M. STEVENS INSTITUTE OF TECHNOLOGY

Locations: Naval Air Systems Command (NAVAIR) installation in Lakehurst, New Jersey, and Hoboken, New Jersey

Certificate Offered: Certificate in Systems Engineering; Certificate in Systems and Supportability Engineering

Program Information:

- Certificate in Systems Engineering
  - Both NAVAIR employees and non-NAVAIR employees can enroll in program
- Certificate in Systems and Supportability Engineering
  - Aimed at working professionals

Admission Requirements:

- Certificate in Systems Engineering
  - Undergraduate degree in engineering or a related field, along with a GPA of 3.0 or better. Outstanding applicants in disciplines other than engineering may be conditionally admitted subject to the satisfactory completion of several 'ramp' courses or the introductory courses within the program

Course Requirements:

- Certificate in Systems Engineering
  - Four courses: "Operational Effectiveness and Life-Cycle Analysis," "Systems Architecture and Design," "Simulation and Modeling," and "Project Management of Complex Systems"
- Certificate in Systems and Supportability Engineering
  - Four courses total:
    - Two core classes – "Systems Operational Effectiveness and Life Cycle Analysis" and "System Architecture and Design"
    - Two electives, drawn from "Systems Supportability and Logistics," "Design for Systems Reliability, Maintainability, and Supportability," and "Decision and Risk Analysis for Complete Systems"

N. UNIVERSITY OF ALABAMA, HUNTSVILLE (UAH) PROFESSIONAL DEVELOPMENT SYSTEMS ENGINEERING PROGRAM

Location: Huntsville, Alabama

Certificate Offered: Systems Engineering Certificate

Program Information:

- Co-sponsored by The Huntsville Chapter of INCOSE and the University of Alabama at Huntsville's (UAH) Professional Development program
- Certificate program was developed with the guidance of the Professional Development Systems Engineering Advisory Committee and in cooperation with the UAH Industrial and Systems Engineering and Engineering Management Department. Composed of senior managers and systems engineering practitioners at the U.S. Army's Aviation and Missile Command (AMCOM) and U.S. Army Space and Missile Defense Command, NASA's Marshall Space Flight Center, and industry, the Advisory Committee designed the program to provide a broader understanding of the systems engineering process and its management application in both private and government sectors
- Program develops appreciation for systems engineering methods across the spectrum of organizational positions, including managers, prospective managers, engineers, analysts, technical specialists, and support personnel

Admission Requirements:

- Undergraduate engineering degree or equivalent experience

Degree Requirements:

- Five core courses, which focus on requirements development; systems engineering; decision making; systems validation and verification; and systems analysis, modification, and simulation
- One elective
  - Electives are offered in program and system management and in risk management

O. UNIVERSITY OF ARIZONA

Location: Tucson, Arizona

Certificate Offered: Professional Graduate Certificate in Systems Engineering

Program Information:

- Offered through University of Arizona Extended University Distance Learning
- Program provides essential education for systems engineers, design engineers, lead engineers, total-life-cycle engineers, senior software systems engineers, and project managers seeking to increase their professional knowledge and advance their careers

Admission Requirements:

- Undergraduate degree in mathematics, physics, or engineering
- Two years' professional experience, beyond the bachelor's

Course Requirements:

- Three core courses
  - "Systems Engineering Models and Methods," "The Systems Engineering Process," "Model-Based Systems Design"
- Two electives
  - Drawn from courses on engineering statistics, simulation modeling and analysis, optimization methods, linear system theory

P. UNIVERSITY OF CALIFORNIA AT IRVINE

Location: Irvine, California

Certificate Offered: Graduate Certificate in Systems Engineering

Program Information:

- Program is relatively new and is geared towards engineers, management personnel and those in other technical and non-technical disciplines who are involved in any aspects of system design, development, production, procurement or support over the entire system life cycle
- Program looks at the systems engineering process as a multifaceted and multi-disciplined function within an organization and focuses on the engineering of systems and systems analysis
- Core courses are offered quarterly
- Classes can also be taken on an individual basis, without enrolling in the program
- Enrollees must also have a cumulative grade of B or better for successful completion of the certificate.

Admission Requirements:

- Applicants must have an undergraduate degree in engineering, computer science, business, or management, plus a minimum of two years of systems-engineering experience or a relevant associate degree with a minimum of 4 years of direct working experience in related fields of systems engineering or management and the consent of the program director

Degree Requirements:

- Four core courses and two electives

Q. UNIVERSITY OF CALIFORNIA, RIVERSIDE

Location: Riverside, California

Certificate Offered: Certificate in Systems Engineering

Program Information:

- "Co-sponsored by the Inland Empire Chapter" of INCOSE and the Bourns School of Engineering at the University of California, Riverside
- Program designed for practicing managers, engineers, analysts, and technical specialists "who need a broader understanding of the systems engineering process and its management applications"
- No admissions requirements, since certificate is offered through the University's continuing education branch

Course Requirements:

- Must complete following five courses with a grade of C or higher:
  - "Systems Engineering Management," "Systems Verification," "System Concepts Development and Selection," "System Requirements Development and Analysis," "Systems Design and Integration"

R. UNIVERSITY OF CALIFORNIA, SAN DIEGO

Location: La Jolla, Sorrento Mesa, North County, and other locations in California

Certificate Offered: Professional Certificate in Systems Engineering

Program Information

- Offered through Extension Programs
- Certificate completed in 3 years, but 18-week (24-session) Intensive Format option available
- Some courses available online

Course Requirements:

- Five core courses
  - "Systems Engineering Management"
  - "Systems Requirements Analysis" (or its online counterpart)
  - "Concept Development"
  - "Systems Validation and Verification"
  - "Systems Engineering Software Overview"
- Electives
  - 3 to 3.5 chosen from among the following:
    - "Systems Software Requirements Engineering"
    - "Systems Hardware and Software Integration"
    - "Systems Engineering Solutions Using Adaptive Rule-Based Simulation"
    - "Systems Requirements Analytical Techniques and Tools"

    - "Program Management Essentials"
    - "Program Management Boot Camp"
- Two Skills-Based Courses
  - "Communication Skills for Technical Professionals"
  - "Oral Communication Skills for Technical Professionals"
- Four INCOSE tutorials in Systems Engineering

S. UNIVERSITY OF IDAHO AT IDAHO FALLS

Location: Idaho Falls, Idaho

Certificate Offered: Certificate in Systems Engineering

Admission Requirements:

- Not available

Course Requirements:

- Four core courses of the university's Master of Engineering program (described in Appendix B, Section A.19)

T. UNIVERSITY OF MINNESOTA

Location: Twin Falls, Minnesota

Certificate Offered: High Level Systems Engineering Certificate

Program Information:

- Will be offered by the Center for Continuing Education
- Currently being designed in partnership with Lockheed-Martin, the University of Virginia, INCOSE Minnesota Chapter, and the Center for Technological Leadership, Department of Mechanical Engineering, and the Carlson School of Management at the University of Minnesota
- Courses are delivered in person and on videotape
  - 1st year: in person and on videotape
  - 2nd and 3rd years: videos converted to online form and delivered via WebCT

Course Requirements:

- "Principles of Systems Engineering"
- "Systems Engineering Management"
- "Systems Engineering Practices I and II"
- "Modeling and Simulation"

U. UNIVERSITY OF MISSISSIPPI-ROLLA/UNIVERSITY OF SOUTHERN CALIFORNIA

Location: Rolla, Missouri/Los Angeles, California

Certificate Offered: Certificate in Systems Engineering

Program Information:

- Program is jointly administered with the University of Southern California (USC) and is aimed at Boeing and affiliated employees
- Boeing employees residing near either UMR or USC can also take classes on these schools' respective campuses if they wish
- Courses are accessible via Internet and satellite and are available for use both at Boeing sites and an enrollee's home
- At present, over 300 Boeing employees are enrolled in the program
- Neither a comprehensive exam nor a thesis is required
- Those who complete the certificate can, if they choose, go on for the Master of Science in Systems Engineering from the University of Missouri, Rolla, which requires six core and four specialty courses
    - Three courses from the certificate program are transferable to the Master of Science in Systems Engineering

Admission Requirements:

- UMR requires a 3.0 grade point average (GPA) and at least 1100 on the Graduate Record Exam (GRE), while USC requires a 3.0 GPA plus "satisfactory" GRE scores (400 verbal, 650 quantitative, and 500 analytical)

Degree Requirements:

- Four core courses, which focus on systems architecting, engineering analysis (two-course sequence), and management
- One specialty-track elective

V. UNIVERSITY OF SOUTHERN CALIFORNIA

Location: Los Angeles, California

Certificate offered: Graduate Certificate in Systems Architecture and Engineering

Program Information:

- Certificate is designed for practicing engineers engaged in the creation and design of complex innovative systems, in aerospace and commercial fields
- With faculty approval, enrollee can apply certificate courses to Masters in Systems Architecture and Engineering

Course Requirements:

- Four courses, drawn from systems architecting, engineering economy, engineering project management, systems engineering theory and practice, management of engineering teams, advanced topics in systems engineering
- One elective from list of courses approved for the Master of Science in Systems Architecture and Engineering, 3 or 4 credit units

W. WICHITA STATE UNIVERSITY

Location: Wichita, Kansas

Certificate Offered: Certificate in Systems Engineering/Management

Program Information:

- Program focuses on the essential knowledge, analytical techniques, and contemporary issues in complex systems definition, design, and decision-making

Course Requirements:

- Prerequisite: Calculus II
- Four courses: "Engineering Management;" "Statistical Methods for Engineers;" "Systems Engineering and Analysis;" and "Analysis of Decision Processes"

APPENDIX D
GLOSSARY

GLOSSARY

AAE	Army Acquisition Executive
ABET	Accreditation Board for Engineering and Technology
ACAT	Acquisition Categories
AEE	Advanced Engineering Environment
AETC	Air Education and Training Command
AF	Air Force
AFIT	Air Force Institute of Technology
AFMC	Air Force Material Command
AFSPC	Air Force Space Command
AFTC	Air Force Training Command
AIA	Aerospace Industrial Association
AIAA	American Institute of Aeronautics and Astronautics
AIS	Automated Information Systems
AMPTIAC	Advanced Materials and Processes Technology Information Analysis Center
APML	Assistant Program Logistics
APMSE	Assistant Program Manager or Systems Engineering
AP	Application Protocol
ASEE	American Society of Engineering Education
ASEO	Army Systems Engineering Office
ASR	Alternative Systems Review
ATI	Advanced Technology Institute
ATL	Acquisition, Technology and Logistics
BMADS	Battlespace Management and Air Defense Systems
BMPCOE	Best Manufacturing Practices Center of Excellence
CAB	Corporate Advisory Board
CCE	College of Continuing Education
CDR	Critical Design Review
CEA	Consumer Electronics Association

CECOM	Communications-Electronics Command
CHENG	Chief Engineer
CIT	Carnegie Institute of Technology
CL	Continuous Learning
CMM	Capability Maturity Model
CMMI	Capability Maturity Model Integration
CMU	Carnegie Mellon University
COE	Center of Excellence
COTR	Contracting Officer's Technical Representative
COTS	Commercial-off-the-shelf
CPIA	Chemical Propulsion Information Agency
CSE	Center for Systems Engineering
CSE	Chief Systems Engineer
CSEE	Corporate Systems Engineering Environment
CTC	Concurrent Technologies Corporation
CUP	Corrosion Under Pain
DARPA	Defense Advanced Research Projects Agency
DAU	Defense Acquisition University
DAWIA	Defense Acquisition Workforce Improvement Act
DEN	Distance Education Network
DISA	Defense Information Systems Agency
DMSO	Defense Modeling and Simulation Office
DoD	Department of Defense
DoE	Department of Energy
DS	Defense Systems
DTIC	Defense Technical Information Center
ECA	Electronic Components, Assemblies
ECPR	Engineering Change Proposal Review
EDRC	Engineering Design Research Center
EIA	Electronic Industries Alliance
EIF	Electronic Industries Foundation
EPIC	Enterprise Process Improvement Collaboration

ERC	Engineering Research Center
ESD	Electrostatic Discharge
ESS	Environmental Stress Screening
EVM	Earned Value Management
EWI	Education with Industry
EX	Exploration Office
FAA	Federal Aviation Administration
FEA	Finite Element Analysis
FIPT	Functional Integrated Product Team
FMECA	Failure Mode, Effects and Criticality Analysis
FRACAS	Failure Reporting and Corrective Action System
FRR	Flight Readiness Review (for airborne systems)
FTA	Fault Tree Analysis
GEIA	Government Electronics and Information Technology Association
GOTS	Government off-the-shelf
HSIAC	Human Systems Information Analysis Center
HTMIAC	High-Temperature Materials Information Analysis Center
IAC	Information Analysis Center
IBR	Integrated Baseline Review
ICAF	Industrial College of the Armed Forces
ICES	Institute for Complex Engineered Systems
IDA	Institute for Defense Analyses
IDSEA	Institute for Defense Systems Engineering and Analysis
IE/EO	Infrared and Electro-Optical
IEC	International Electrotechnical Commission
IEEE	Institute of Electronic and Electrical Engineers
IJWA	Institute for Joint Warfare Analysis
INCOSE	International Council on Systems Engineering
IPD	Integrated Product Development
IPPD	Integrated Product and Process Development
IPT	Integrated Product Team

IRIA	Infrared Information Analysis Center
IS	Interim Standard
ISO	International Organization for Standardization
ISR	Institute for Systems Research
ISS	International Space Station
ITR	Initial Technical Review
JANNAF	Joint Army-Navy-Air Force
JPL	Jet Propulsion Laboratory
JTA	Joint Technical Architecture
JTA-A	Joint Technical Architecture-Army
JTCG/AS	Joint Technical Coordinating Group on Aircraft Survivability
JTCG/ME	Joint Technical Coordinating Group and Munitions Effectiveness
LAI	Lean Aerospace Initiative
MARCAV	Mid-Atlantic Regional Consortium for Advanced Vehicles
MARCORSYSCOM	Marine Corps Systems Command
MDA	Milestone Decision Authority
MEMS	Micro Electro-Mechanical Systems
MIAC	Metals Information Analysis Center
MMCIAC	Metal Matrix Composites Information Analysis Center
MPT	Manpower, Personnel and Training
MS	Master of Science
MSIAC	Modeling and Simulation Information Analysis Center
MTIAC	Manufacturing Technology Information Analysis Center
NAE	National Academy of Engineering
NAS	National Aerospace System
NASA	National Aeronautics and Space Administration
NAVAIR	Naval Air Systems Command Initiatives
NAVSEA	Naval Sea Systems Command
NCEE	Naval Collaborative Engineering Environment
NCEMT	National Center for Excellence in Metalworking Technology
NCSOSE	National Center for System of Systems Engineering

NDCEE	National Defense Center for Environment Excellence
NDIA	National Defense Industrial Association
NDT	Nondestructive Testing
NDU	National Defense University
NIST	National Institute of Standards and Technology
NNSA	National Nuclear Security Administration
NPS	Naval Post Graduate School
NSF	National Science Foundation
NSIA	National Security Industries Association
NSWCDD	Naval Surface Warfare Center, Dahlgren Division
NTSA	National Training Systems Association
ODU	Old Dominion University
OM	Mission Integration
OMG	Object Management Group
OSD	Office of the Secretary of Defense
OSS&E	Operational Safety, Suitability, and Effectiveness
OTRR	Operation Test Readiness Review
PCR	Physical Configuration Review
PDR	Preliminary Design Review
PLASTEC	Plastics Information Analysis Center
PSE	Project Solving Environment
R&D	Research and Development
RAC	Reliability Analysis Center
RCM	Reliability-Centered Maintenance
RDA	Research, Development and Acquisition
REDEC	Research Development and Engineering Center
RMAIT	Resource Management Analysis and Integration Team
SAE	Society and Information Engineers
SAM	Systems Appraisal Method
SC	Subcommittees
SE CoP	Systems Engineering Community of Practice
SE	Systems Engineering

SEBoK	Systems Engineering Body of Knowledge
SEC	Systems Engineering Committee
SECAM	Systems Engineering Capability Assessment Model
SECM	Systems Engineering Capability Model
SECO	Systems Engineering Center of Excellence
SED	Systems Engineering Division
SEDRES	Systems Engineering Data Representation and Exchange Standardization
SEDSIG	Systems Engineering Domains Special Interest Group
SEI	Software Engineering Institute
SEMDA	Systems Engineering Modeling and Design Analysis
SEP	Systems Engineering Plan
SEPO	Systems Engineering Process Office
SEPWG	Systems Engineering Process Working Group
SER	Systems Engineering Revitalization
SETC	Systems Engineering Technical Committee
SETR	Systems Engineering Technical Review
SFR	System Functional Review
SMC	Space and Missile Systems Center
SOLE	Society of Automotive Engineers
SPRDE	Systems Planning, Research, Development and Engineering
SRC	Systems Research Center
SRR	System Requirements Review
SS	Supplier Source
SSP	Stockpile Stewardship Program
STEP	Standard for the Exchange of Product
SURVIAC	Survivability/Vulnerability information Analysis Center
SVR/PRR	System Verification Review/Production Readiness Review
SW	Software
SWRI	Southwest Research Institute
TAG	Technical Advisory Group
TAT	Technical Area Task

TC	Technical Committee
TIA	Telecommunications Industry Association
TRR	Test Readiness Review
ULM	Unified Modeling Language
UMN	University of Minnesota
US PRO	U.S. Product Data Association
USACE	U.S. Army Corps of Engineers
USAF	United States Air Force
USD	Under Secretary of Defense
VIPeR	Vehicle Integration Performance and Resources
VPI	Virginia Polytechnic Institute
WCCA	Worst Case Circuit Analysis
WMD	Weapons of Mass Destruction
WPAFB	Wright-Patterson Air Force Base
WSTIAC	Weapon Systems Technology Information Analysis Center
YES	Year of the Engineer and Scientist

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14. ABSTRACT

This document explores the different ongoing activities within the government, academia, and industry to promote the discipline of systems engineering and its implementation. The focus is systems engineering within the defense community, although attention is given to non-defense endeavors both within the United States and internationally. The research for this document took place from roughly spring 2003–fall 2004; therefore, the activities presented in this document represent merely a snapshot in time. For this reason, readers are encouraged to seek the most up-to-date information on an activity via the various links provided. The following topics are included: DoD efforts in systems engineering; systems engineering efforts in other government agencies; systems engineering associations, standards and models; academic opportunities for systems engineering; and systems engineering-related academies, centers, and laboratories. Three appendices give details on the undergraduate, graduate, and certificate programs available in systems engineering in the United States as of January 2004.

15. SUBJECT TERMS

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systems engineering associations, standards and models
systems engineering-related academies, centers, and laboratories
undergraduate programs, graduate programs, and certificate programs in systems engineering

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